



US009465020B2

(12) **United States Patent**
Christian et al.

(10) **Patent No.:** **US 9,465,020 B2**
(45) **Date of Patent:** **Oct. 11, 2016**

(54) **METHODS, APPARATUS AND SYSTEMS
FOR MEASURING SNOW STRUCTURE AND
STABILITY**

(71) Applicant: **AvaTech, Inc.**, Park City, UT (US)
(72) Inventors: **James Loren Christian**, Park City, UT
(US); **Samuel Tileston Whittemore**,
Readfield, ME (US); **Brinton J. W.**
Markle, Cambridge, MA (US)
(73) Assignee: **AvaTech, Inc.**, Park City, UT (US)
(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/827,553**

(22) Filed: **Aug. 17, 2015**

(65) **Prior Publication Data**

US 2015/0355152 A1 Dec. 10, 2015

Related U.S. Application Data

(63) Continuation of application No. 14/063,557, filed on
Oct. 25, 2013.

(60) Provisional application No. 61/822,284, filed on May
10, 2013, provisional application No. 61/718,471,
filed on Oct. 25, 2012.

(51) **Int. Cl.**
G01N 11/10 (2006.01)
G01N 33/18 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **G01N 33/18** (2013.01); **G01B 5/30**
(2013.01); **G01B 7/26** (2013.01); **G01B 11/14**
(2013.01); **G01B 21/18** (2013.01); **G01N 3/00**
(2013.01); **G01N 3/08** (2013.01); **G01N 3/42**
(2013.01);
(Continued)

(58) **Field of Classification Search**
None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,988,923 A 11/1976 Elmiger et al.
4,820,051 A 4/1989 Yanagisawa et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN 201010300760 * 1/2011
DE 19503017 A 9/1995

(Continued)

OTHER PUBLICATIONS

Floyer, J. and Jamieson, B., "Avalanche Weak Layer Tracing and
Detection in Snow Penetrometer Profiles," Proceedings of the 4th
Canadian Conference on Geohazards: From Causes to Manage-
ment, Presse de l'Université Laval, Québec, 8 pages (2008).

(Continued)

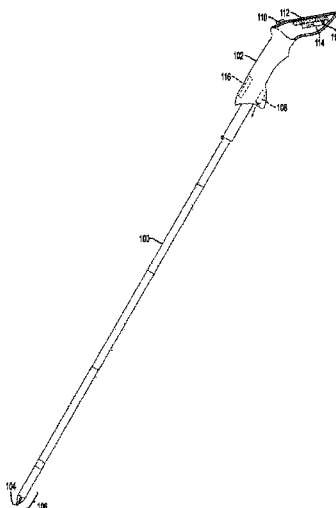
Primary Examiner — Robert R Raeviss

(74) *Attorney, Agent, or Firm* — Downs Rachlin Martin
PLLC

(57) **ABSTRACT**

The present inventions relate generally to methods, appara-
tus and systems for measuring snow stability and structure
which may be used to assess avalanche risk. The disclosed
apparatus includes a sensing unit configured to sense a
temperature of a layer of snow as the sensing unit is being
driven into the layer of snow. The disclosed apparatus may
also be configured to take other environmental measure-
ments, including resistance to penetration, humidity, grain
size, slope aspect and inclination. Methods and apparatus are
also disclosed for generating a profile of snow layer tem-
perature according to depth based on the sensed temperature.
Systems and apparatus are also disclosed for sharing the
generated profiles among a plurality of users via a central
server, and for evaluating an avalanche risk at a geographic
location.

21 Claims, 25 Drawing Sheets



- (51) **Int. Cl.**
G01N 9/00 (2006.01)
G01N 3/08 (2006.01)
G01N 3/60 (2006.01)
G01B 11/14 (2006.01)
G01B 5/30 (2006.01)
G01W 1/14 (2006.01)
G01B 21/18 (2006.01)
G01N 3/00 (2006.01)
G01N 17/00 (2006.01)
G01B 7/26 (2006.01)
G08C 17/02 (2006.01)
G01N 3/42 (2006.01)

- (52) **U.S. Cl.**
 CPC **G01N 3/60** (2013.01); **G01N 9/00** (2013.01);
G01N 11/10 (2013.01); **G01N 17/00**
 (2013.01); **G01W 1/14** (2013.01); **G08C 17/02**
 (2013.01); **G01N 2033/1873** (2013.01); **G01N**
2203/0082 (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

- | | | | |
|-------------------|---------|------------------|-------------------------|
| 5,211,249 A | 5/1993 | Richter et al. | |
| 5,661,464 A | 8/1997 | Bilak et al. | |
| 5,831,161 A | 11/1998 | Johnson et al. | |
| 5,871,025 A | 2/1999 | Richter | |
| 6,119,535 A * | 9/2000 | Tambo | G01F 23/243
73/865.8 |
| 6,182,514 B1 | 2/2001 | Hodges | |
| 6,313,645 B1 | 11/2001 | Brandelik et al. | |
| 6,351,988 B1 | 3/2002 | Bartlett | |
| 6,530,284 B1 | 3/2003 | Tambo et al. | |
| 6,957,593 B1 | 10/2005 | Burns | |
| 7,040,146 B2 | 5/2006 | Mackenzie et al. | |
| 7,564,477 B2 | 7/2009 | Kirby | |
| 7,628,059 B1 | 12/2009 | Scherbring | |
| 2005/0076709 A1 | 4/2005 | Mackenzie et al. | |
| 2006/0171579 A1 | 8/2006 | Lee et al. | |
| 2008/0198027 A1 | 8/2008 | Bugge | |
| 2010/0148946 A1 | 6/2010 | Strombeck et al. | |
| 2011/0226044 A1 | 9/2011 | Hughes et al. | |
| 2012/0004848 A1 | 1/2012 | Kinast et al. | |
| 2012/0234102 A1 * | 9/2012 | Johnson | G01N 11/10
73/826 |
| 2012/0242488 A1 | 9/2012 | Wilson | |

- | | | |
|-----------------|---------|------------------|
| 2014/0116127 A1 | 5/2014 | Christian et al. |
| 2014/0116157 A1 | 5/2014 | Christian et al. |
| 2014/0116162 A1 | 5/2014 | Christian et al. |
| 2014/0118165 A1 | 5/2014 | Christian et al. |
| 2014/0366648 A1 | 12/2014 | Christian et al. |

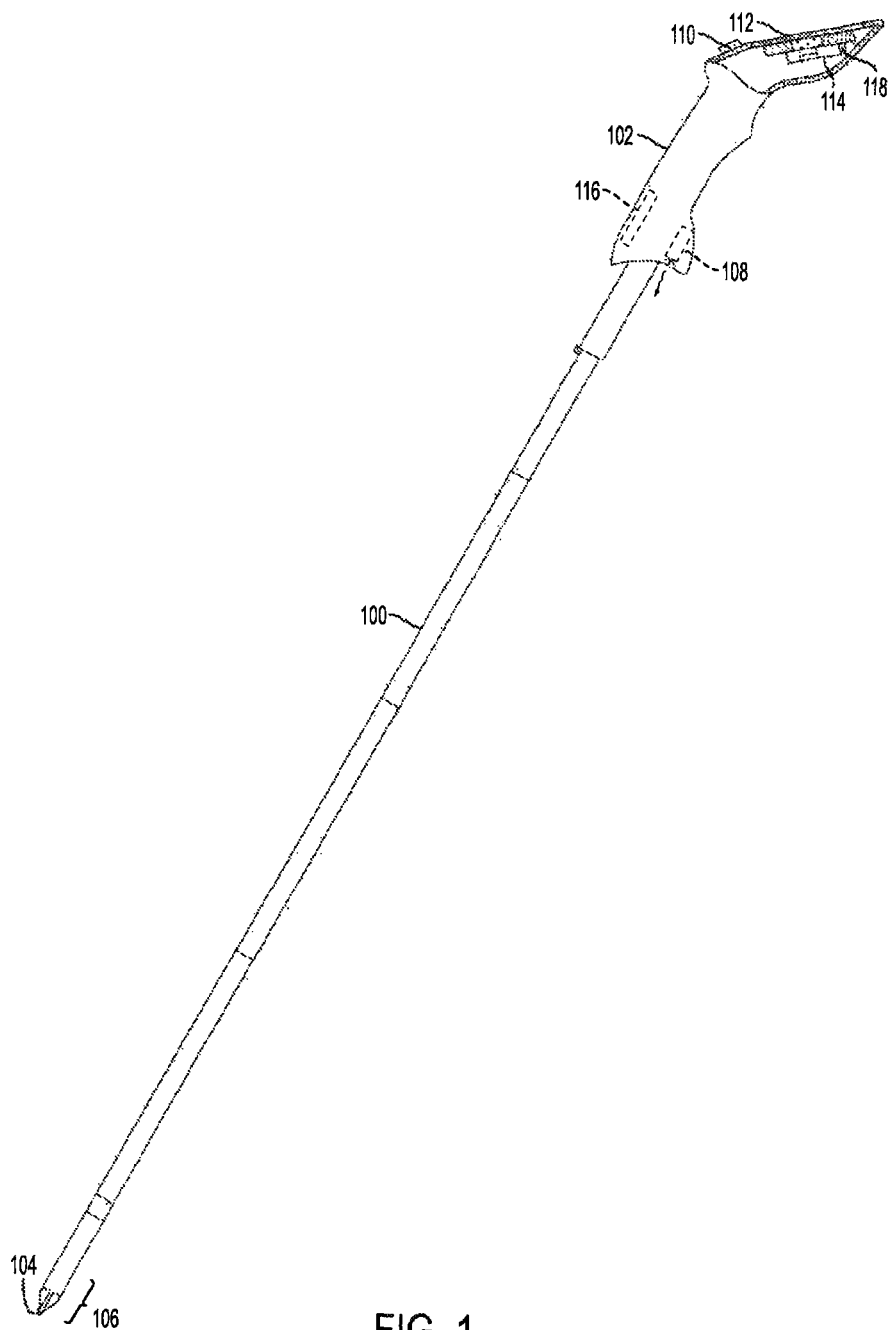
FOREIGN PATENT DOCUMENTS

- | | | |
|----|----------------|--------|
| EP | 0760989 A1 | 3/1997 |
| EP | 1202078 A2 | 5/2002 |
| EP | 2444132 A1 | 4/2012 |
| JP | H0666957 A | 3/1994 |
| WO | WO-03056302 A1 | 7/2003 |
| WO | 2014066852 A2 | 5/2014 |

OTHER PUBLICATIONS

- Floyer, J. A. and Jamieson, J. B., "Rate-effect experiments on round-tipped penetrometer insertion into uniform snow," J. Glaciol., vol. 56, No. 198, pp. 664-672 (2010).
- Mackenzie, R and Payten, W., "A Portable, Variable-Speed, Penetrometer for Snow Pit Evaluation; Mountain Snowpack," International Snow Science Workshop, Penticton, B.C., pp. 294-300 (2002).
- Sakoe, H. et al., "Dynamic Programming Algorithm Optimization for Spoken Word Recognition," IEEE Transactions on Acoustics, Speech and Signal Processing, vol. ASSP-26, No. 1, pp. 43-49 (Feb. 1978).
- Schneebeli, M. et al., "Measuring Snow Microstructure and Hardness Using a High Resolution Penetrometer," Cold Regions Science and Technology, vol. 30, No. 1-3, pp. 305-311 (1999).
- Schweizer, J. et al., "Measurements of Human-Triggered Avalanches from the Swiss Alps," Proceedings International Snow Science Workshop, Big Sky, Montana, pp. 1-8 (Oct. 2-6, 2000).
- Wang, K. et al., "Alignment of Curves by Dynamic Time Warping," The Annals of Statistics, vol. 25, No. 3, pp. 1251-1276 (1997).
- International Search Report and Written Opinion in International Application No. PCT/US2015/037761, dated Sep. 29, 2015.
- International Search Report and Written Opinion in International Application No. PCT/US2013/066962, dated May 2, 2014.
- Non-Final Office Action dated Feb. 22, 2016, in co-pending U.S. Appl. No. 14/063,557, entitled "Methods, Apparatus and Systems for Measuring Snow Structure and Stability."
- Supplementary European Search Report in related European Patent Application No. 13849814.2, entitled "Methods, Apparatus and Systems for Measuring Snow Structure and Stability."

* cited by examiner



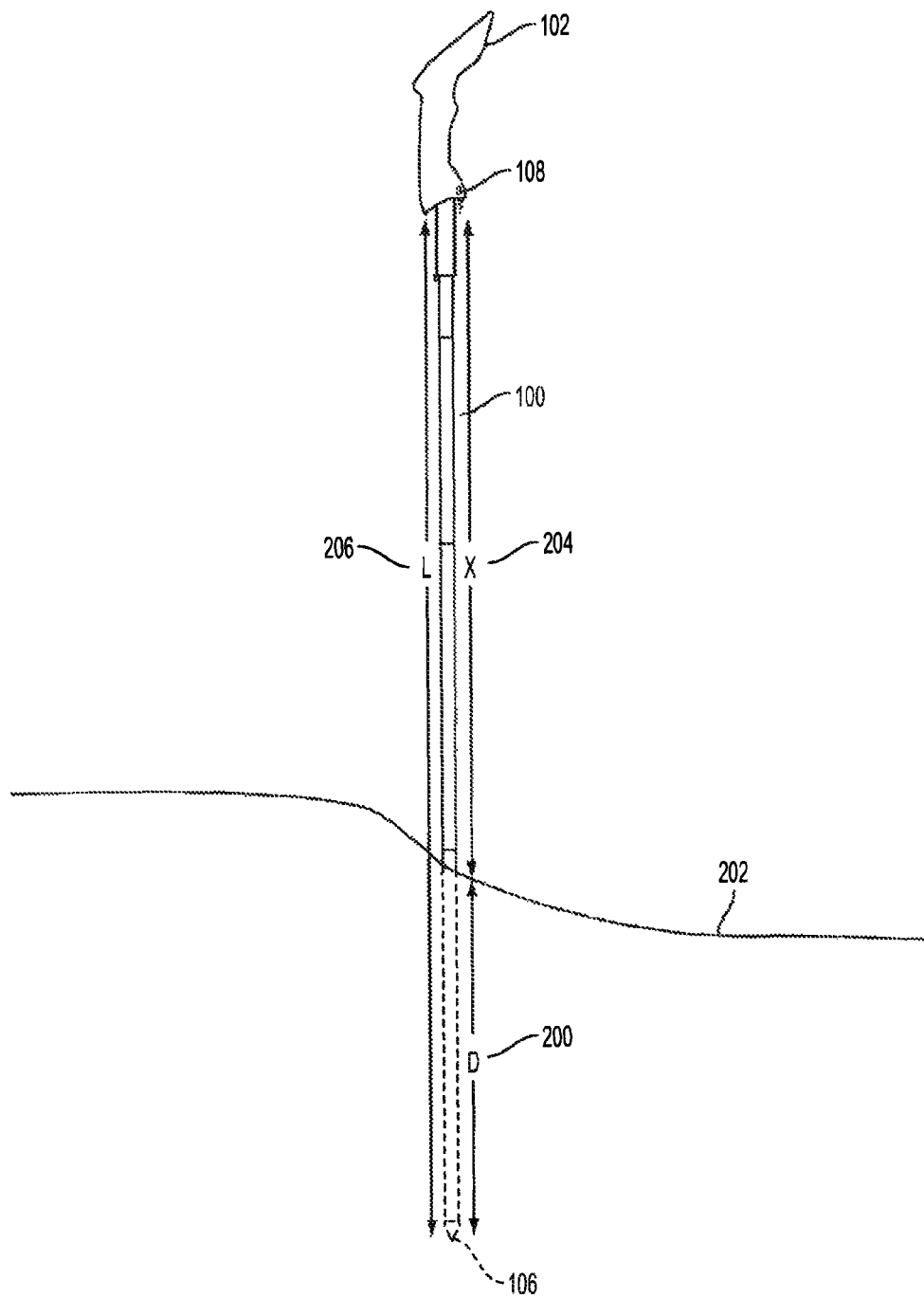


FIG. 2A

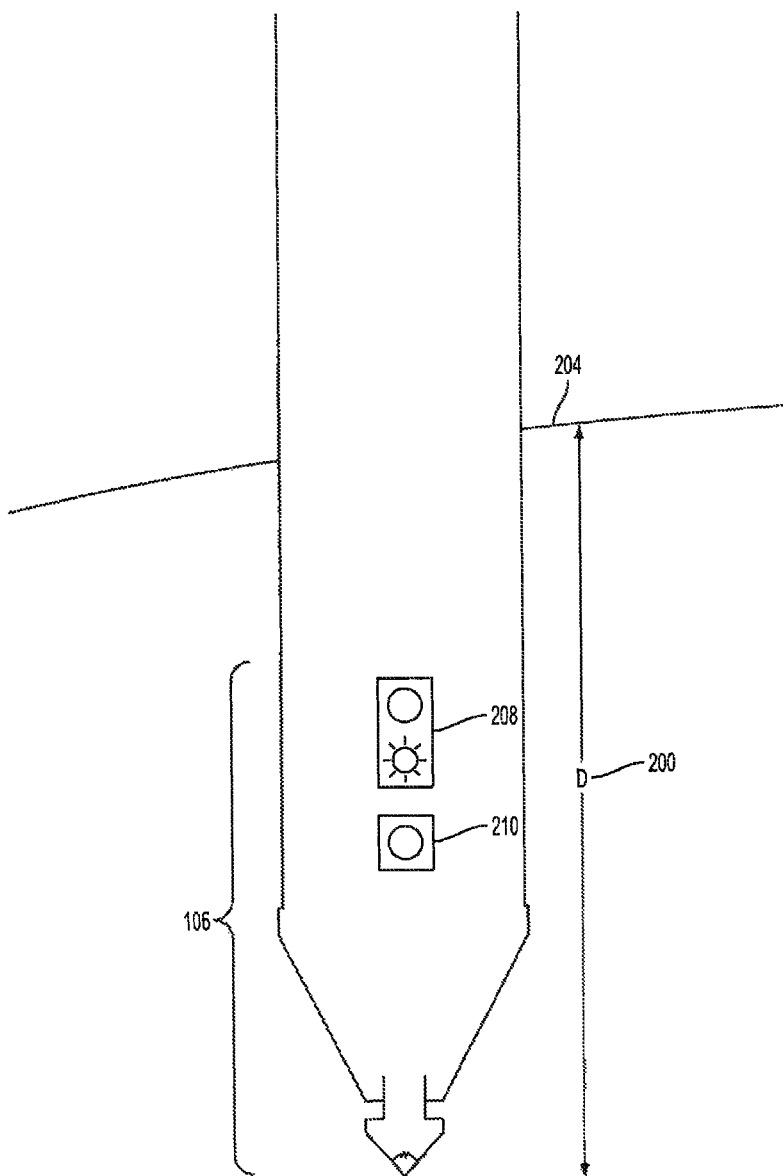


FIG. 2B

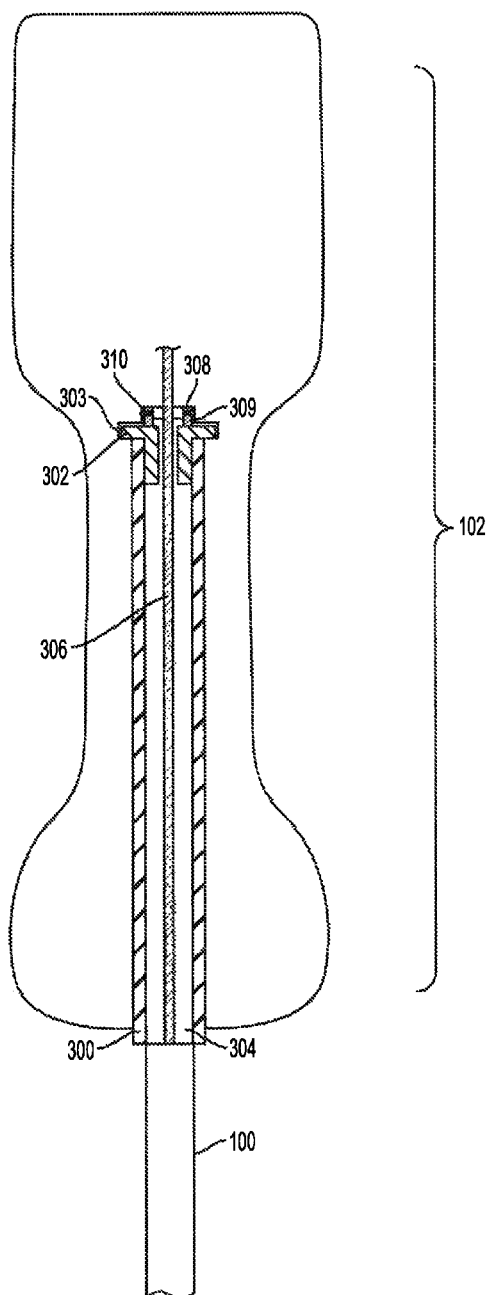


FIG. 3A

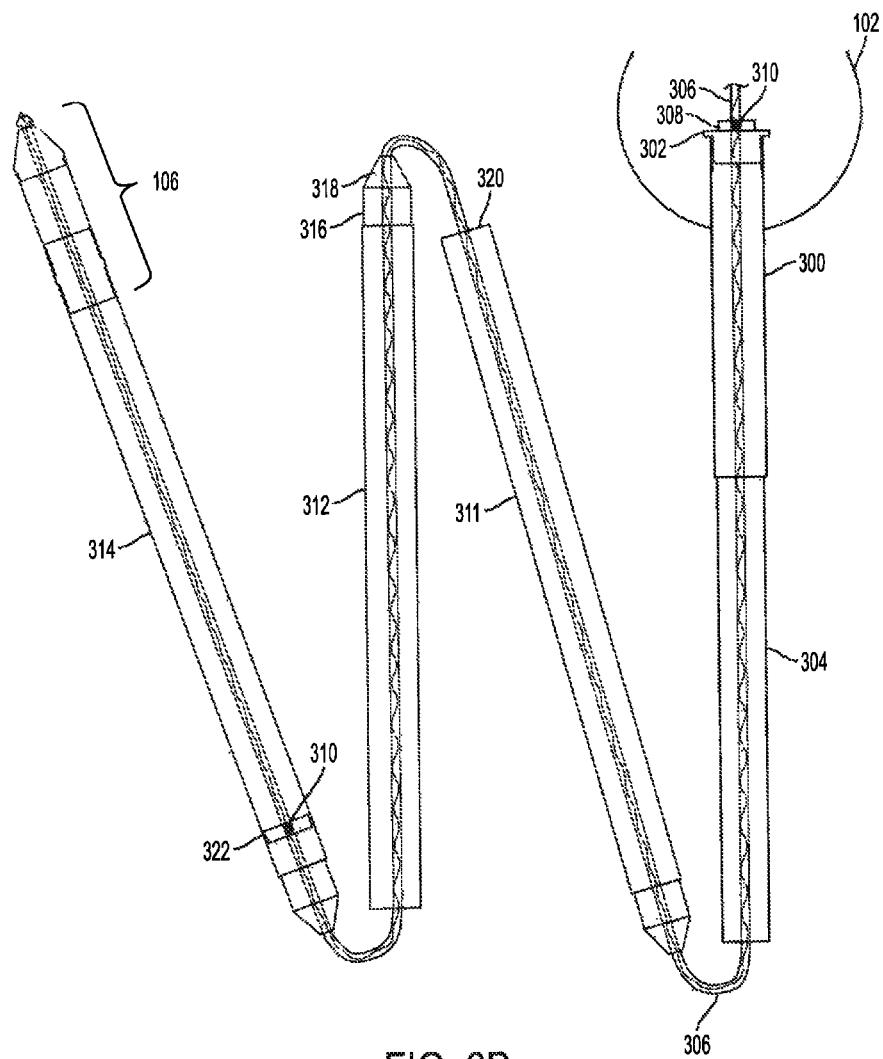


FIG. 3B

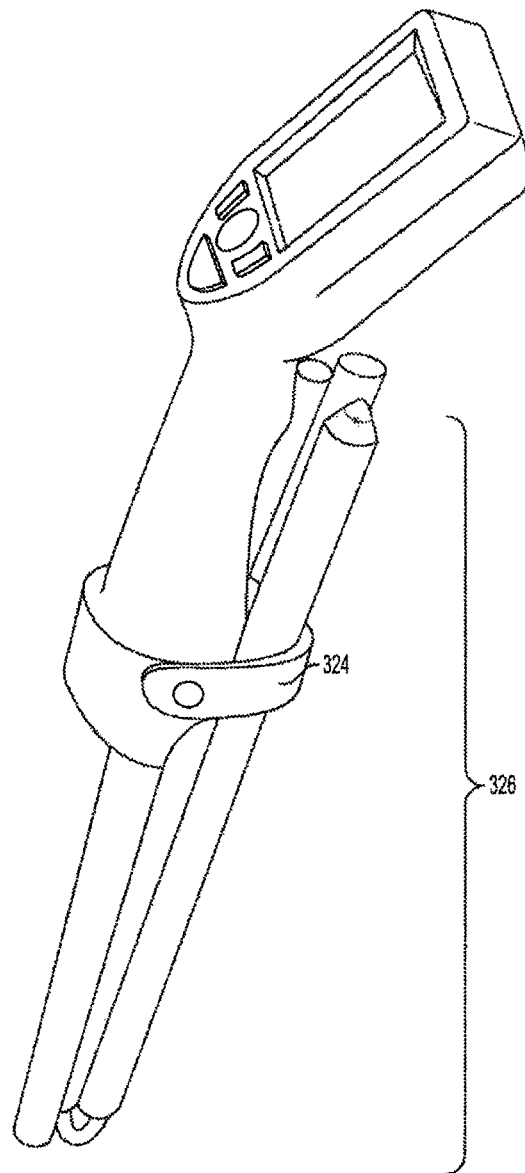


FIG. 3C

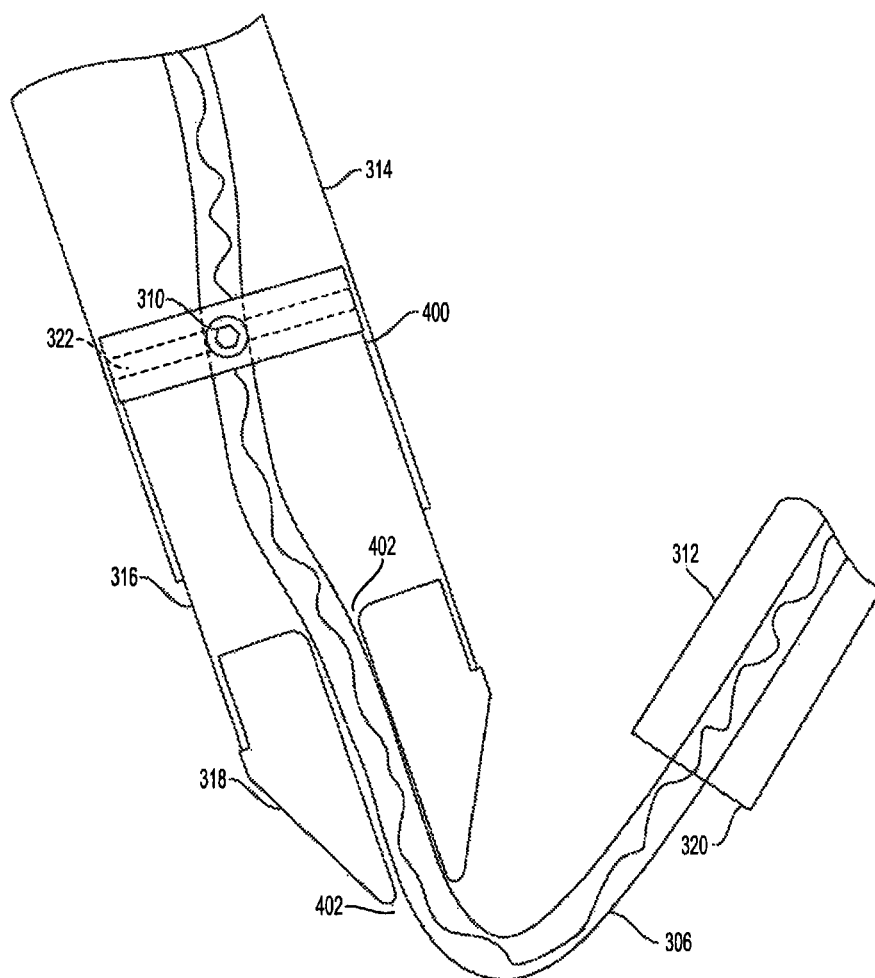


FIG. 4

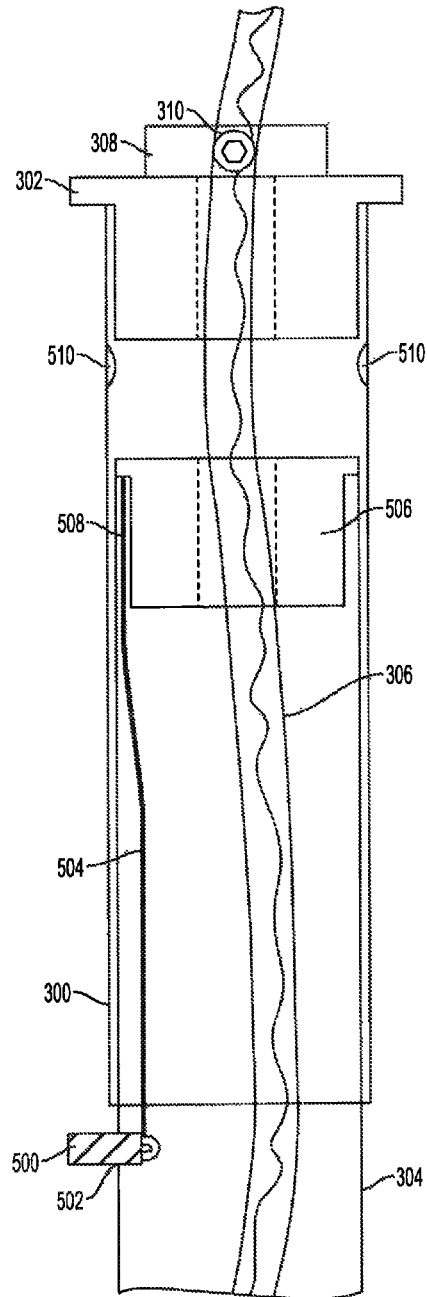


FIG. 5

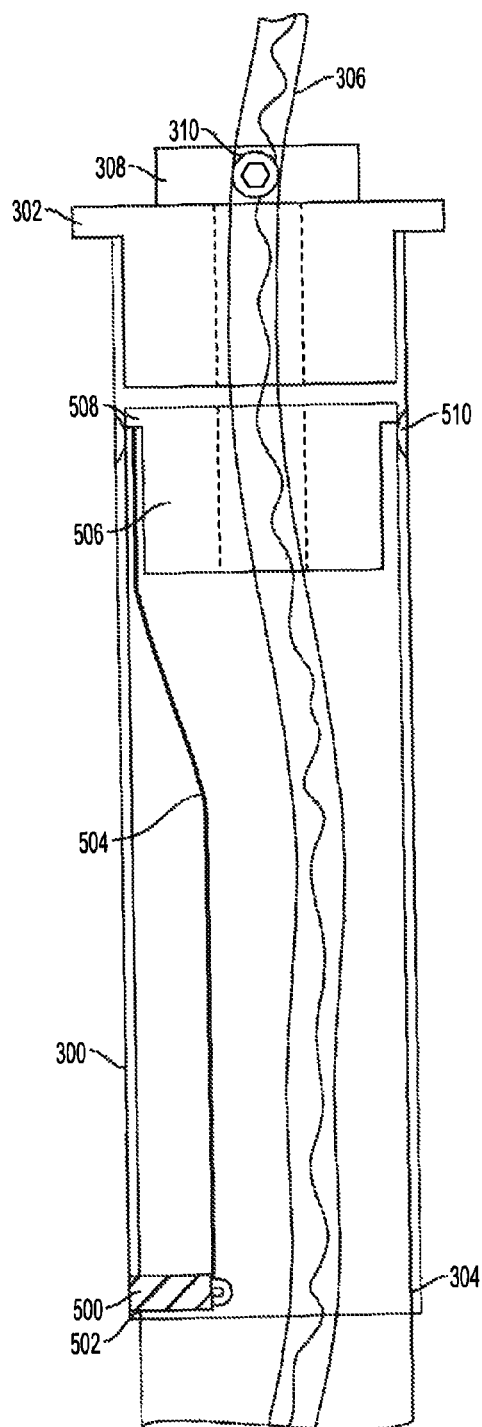


FIG. 6

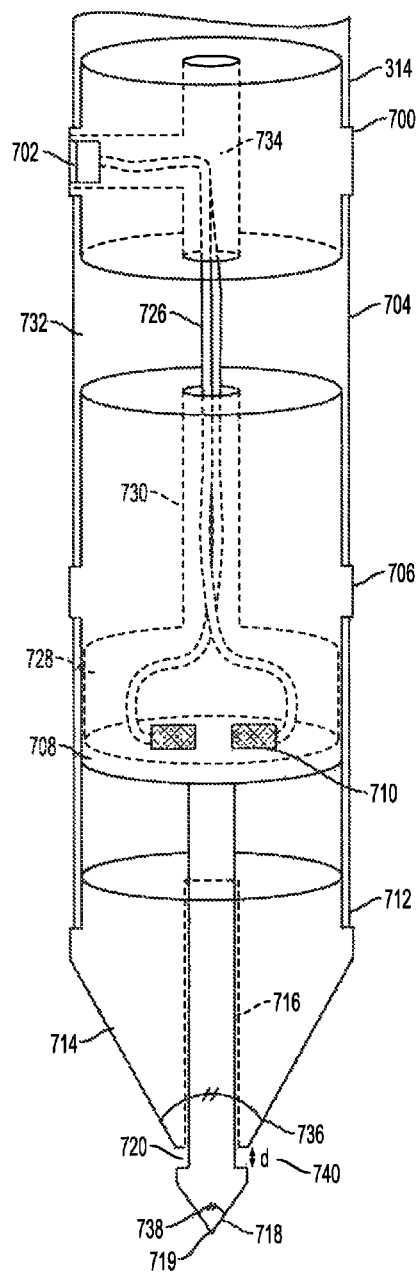


FIG. 7

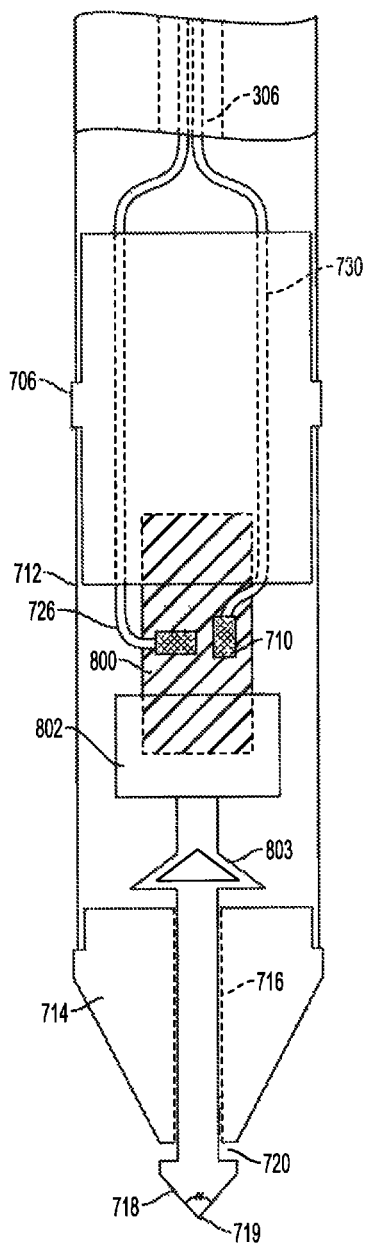


FIG. 8A

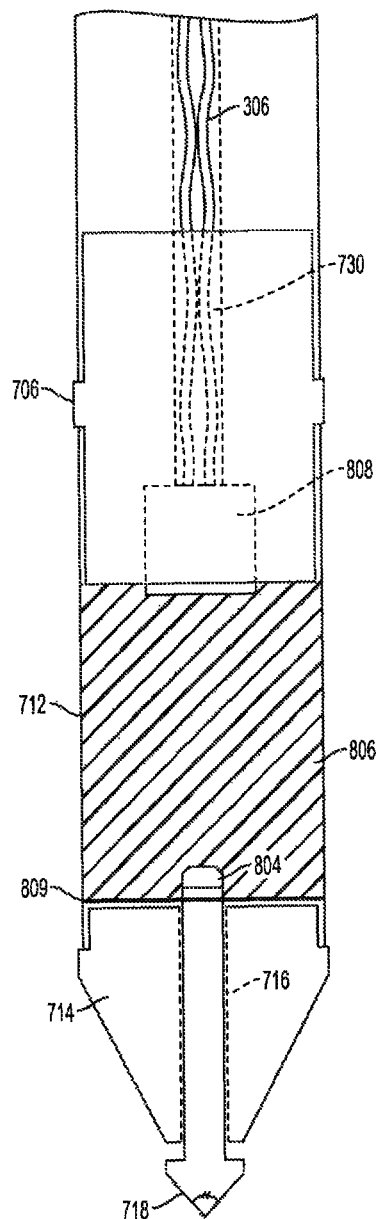


FIG. 8B

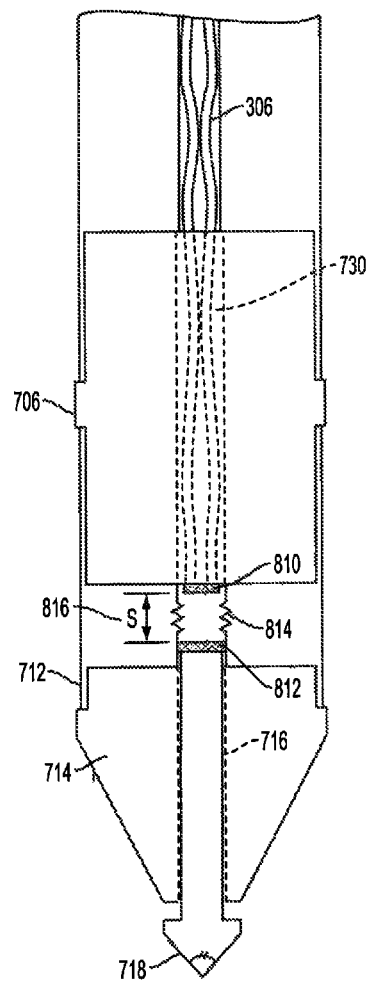


FIG. 8C

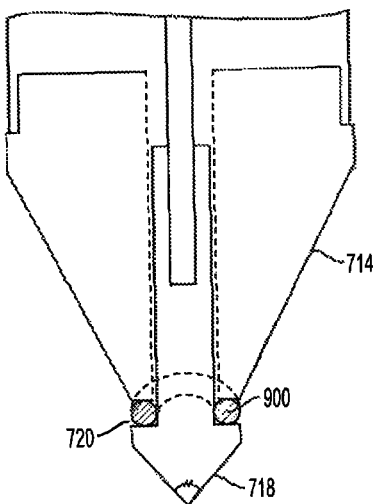


FIG. 9

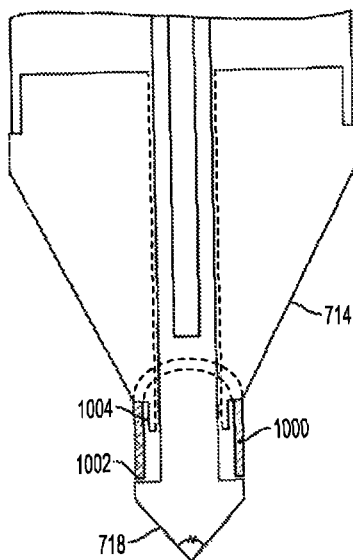


FIG. 10

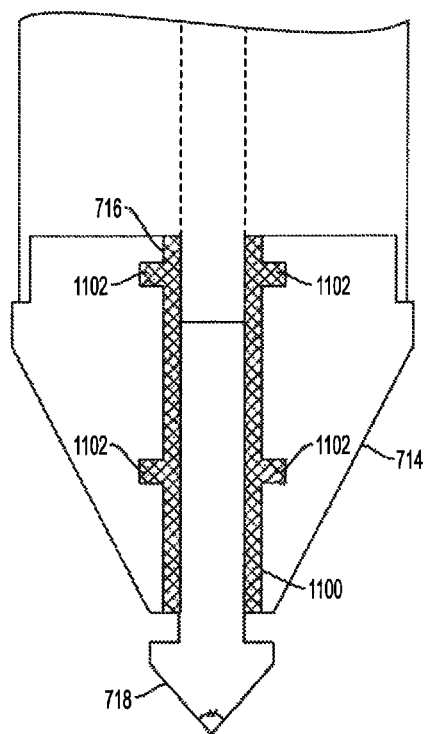


FIG. 11

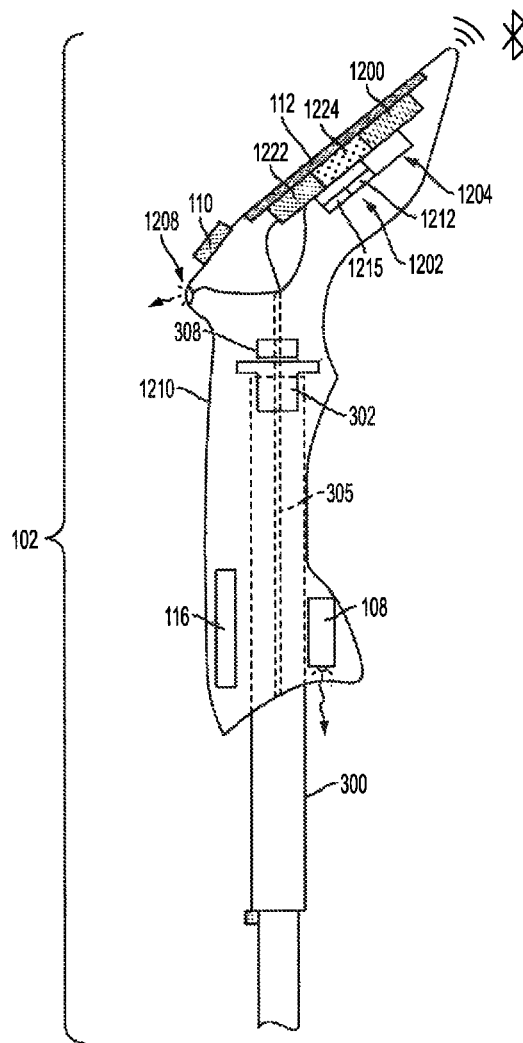


FIG. 12A

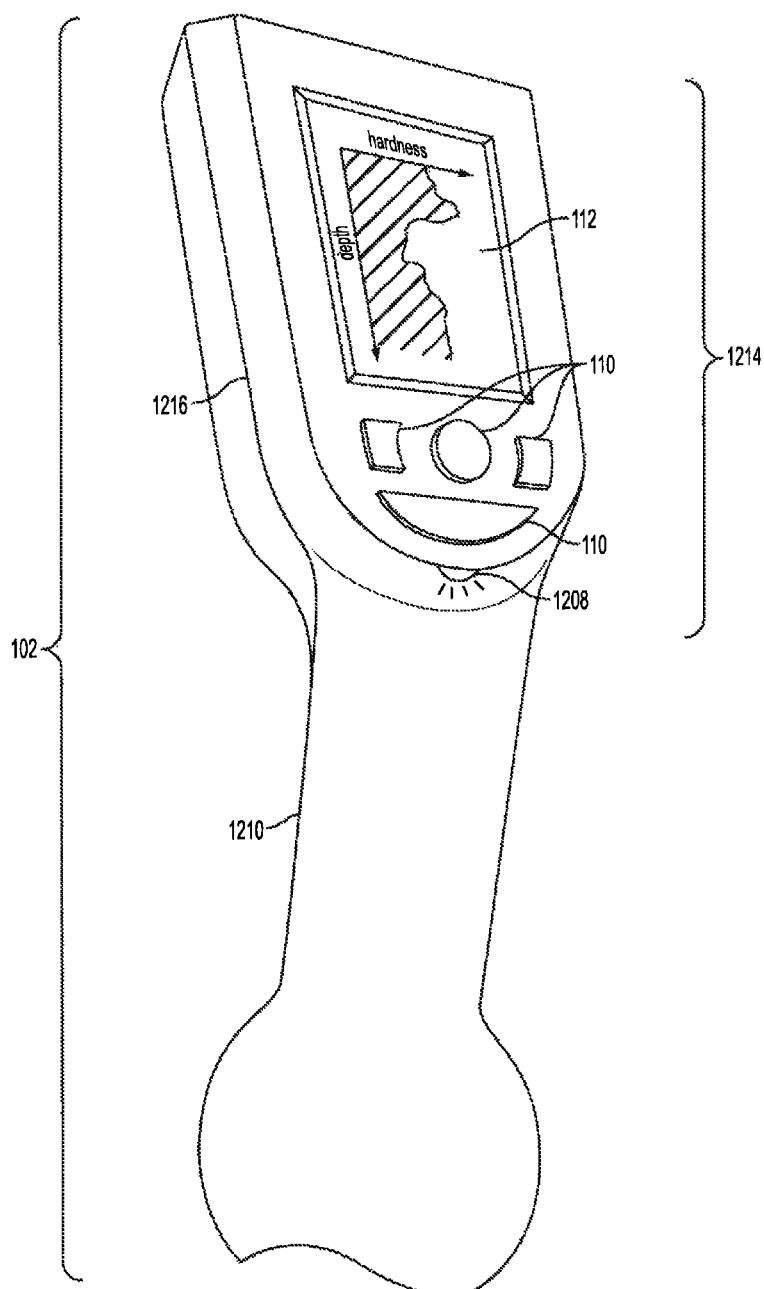


FIG. 12B

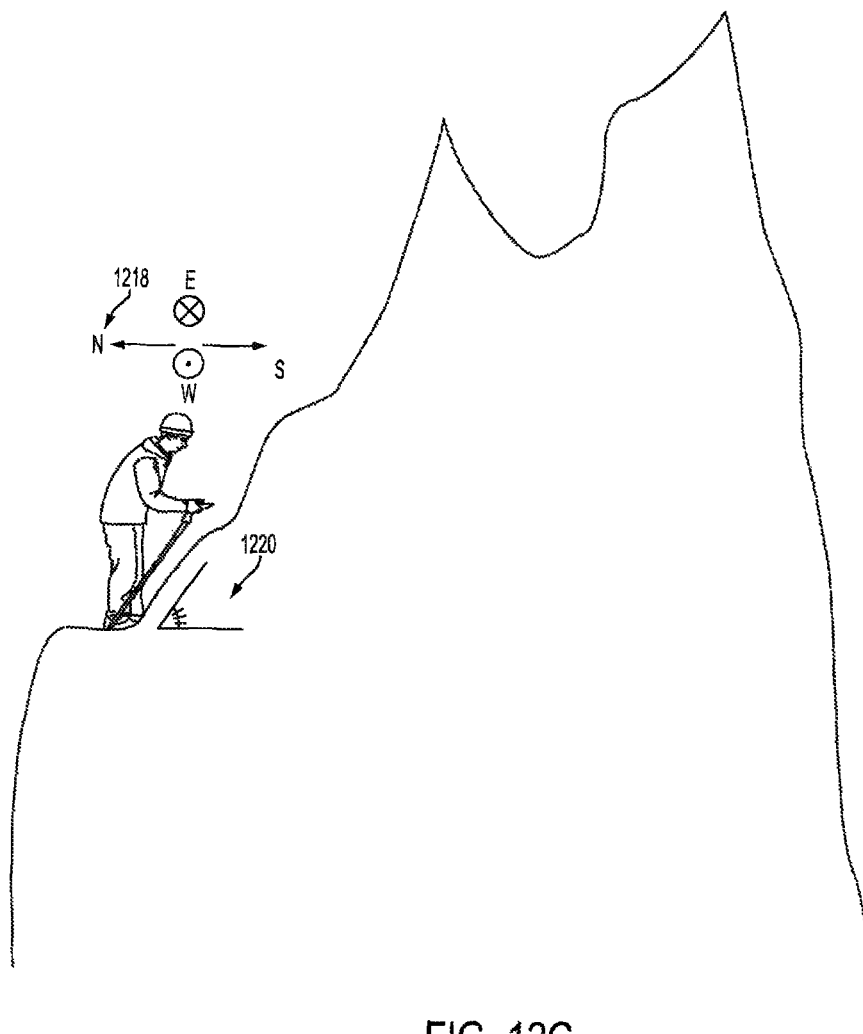


FIG. 12C

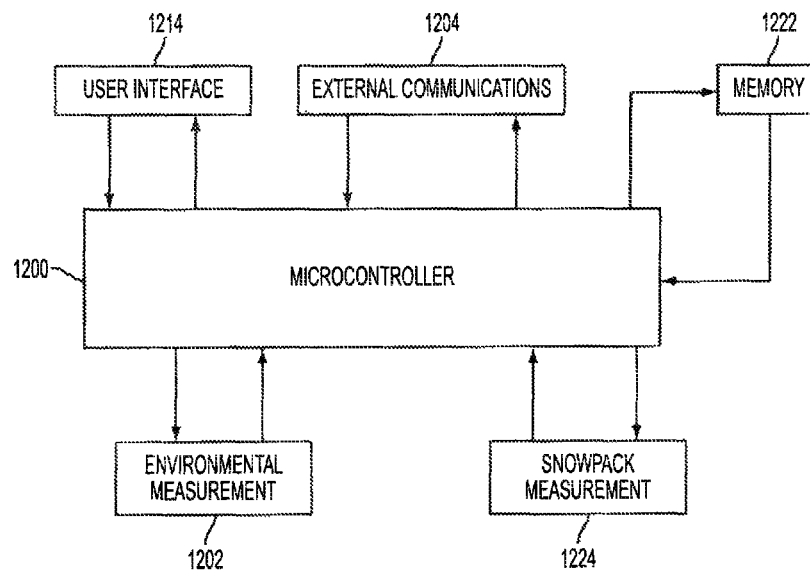


FIG. 13

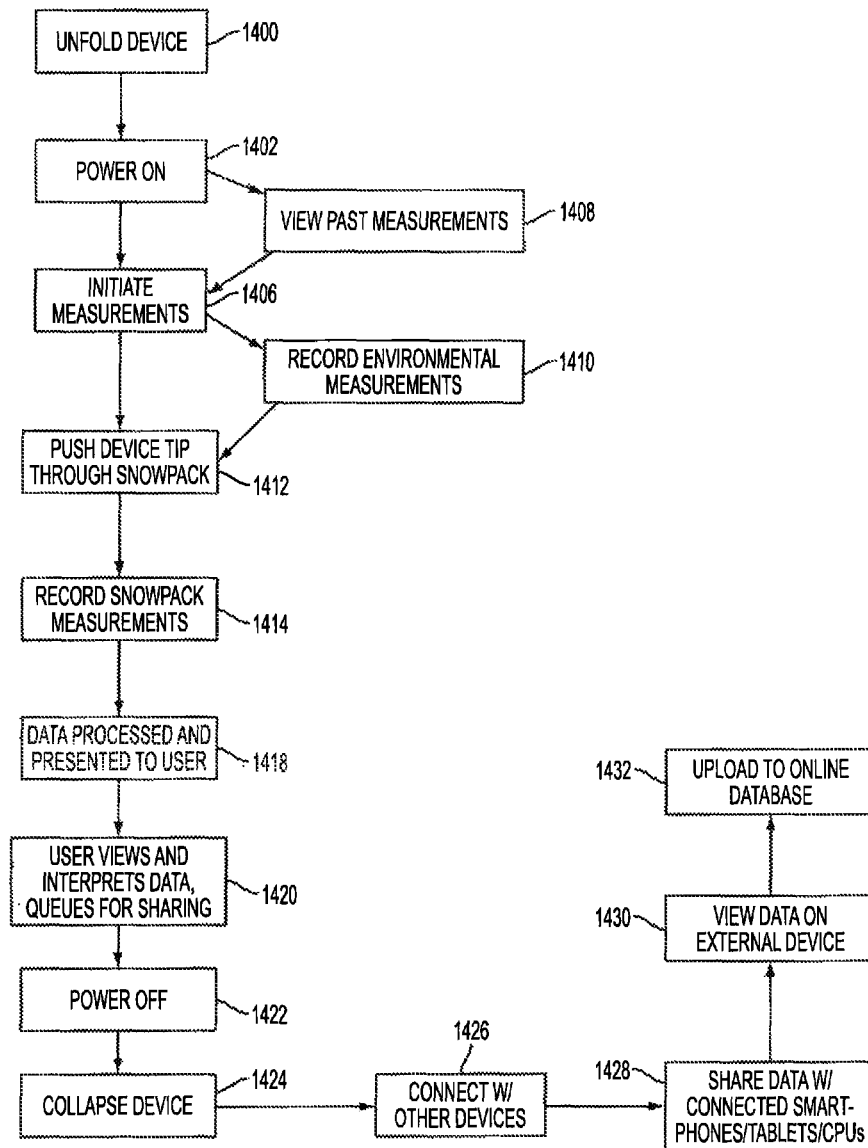


FIG. 14

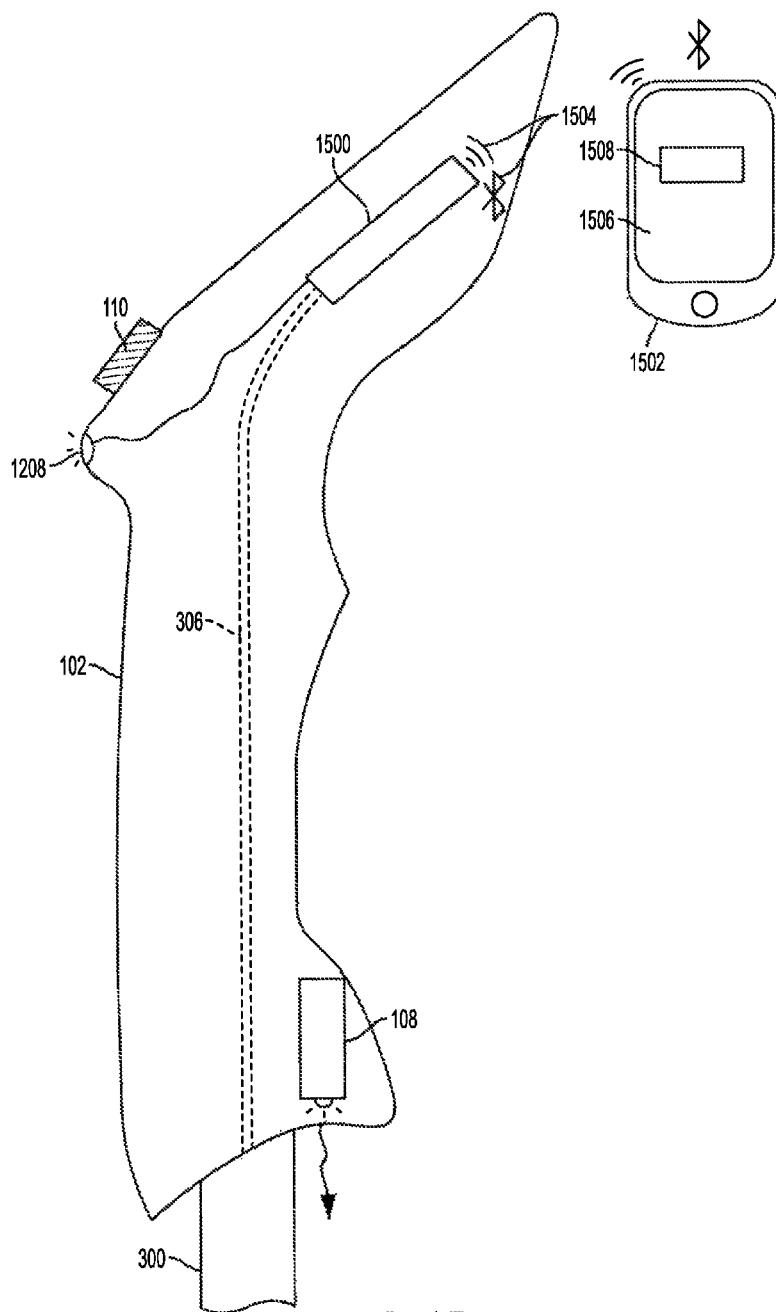


FIG. 15

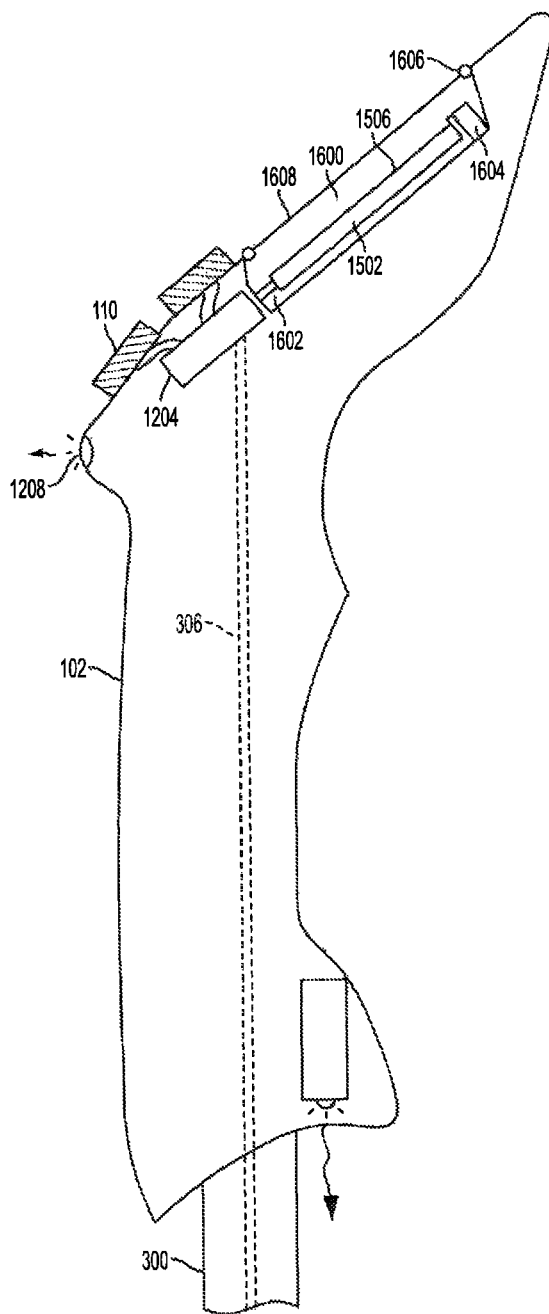


FIG. 16

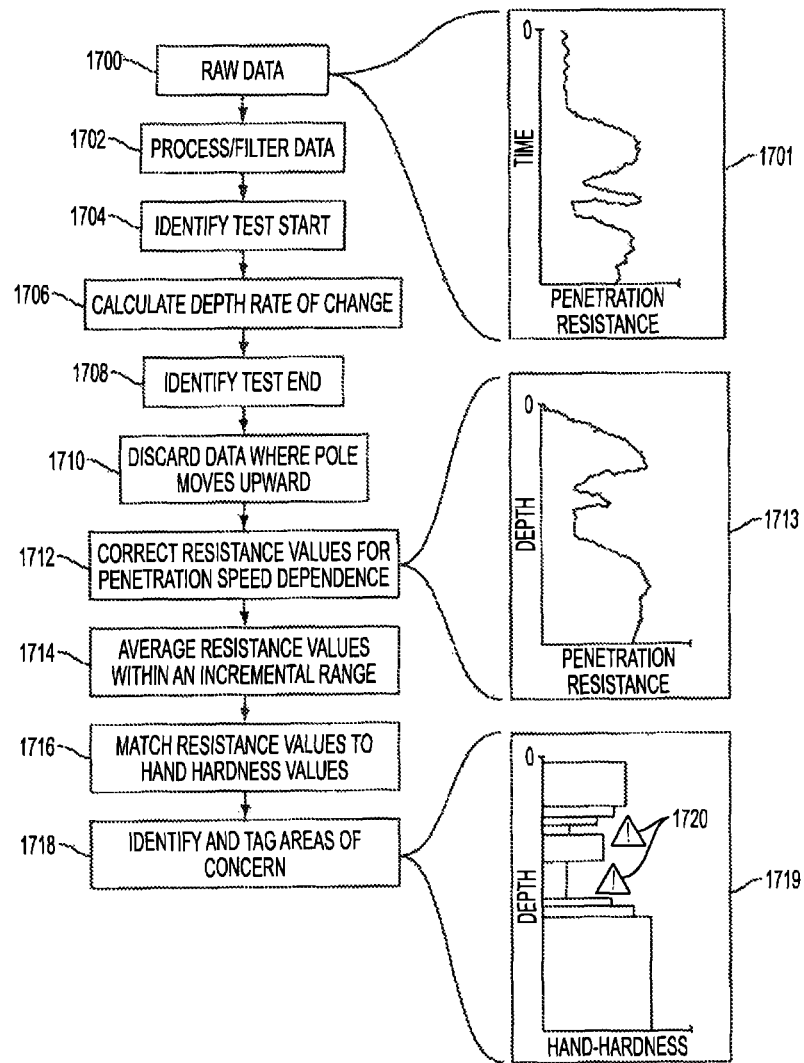


FIG. 17

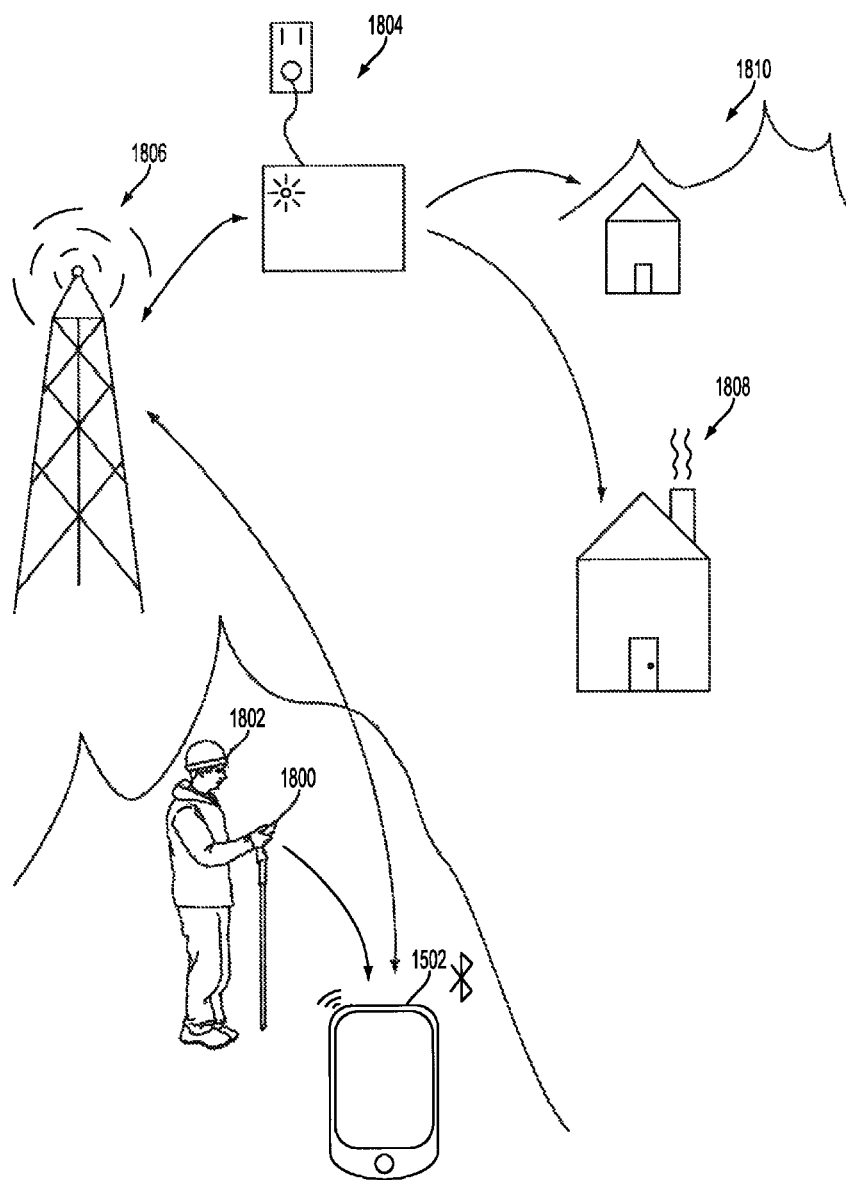


FIG. 18

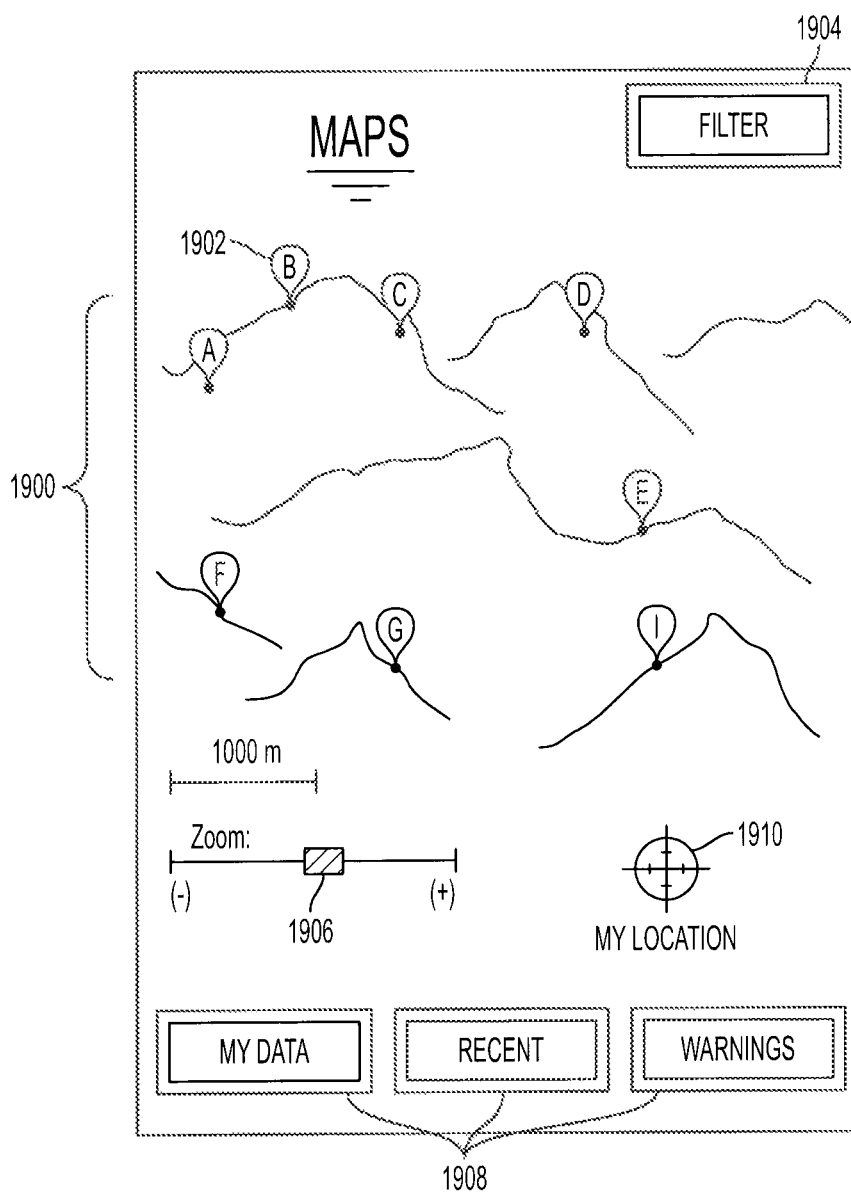


FIG. 19

1

METHODS, APPARATUS AND SYSTEMS FOR MEASURING SNOW STRUCTURE AND STABILITY

This application is a Continuation of U.S. patent application Ser. No. 14/063,557, entitled METHODS, APPARATUS AND SYSTEMS FOR MEASURING SNOW STRUCTURE AND STABILITY, filed Oct. 25, 2013, which claims the benefit of priority to U.S. Provisional Application Nos. 61/718,471 filed Oct. 25, 2012 and 61/822,284 filed May 10, 2013, all of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

The present disclosure relates to a portable device for assessing the structure and stability of a layer of snow.

BACKGROUND

Every year, hundreds of people around the world die in avalanches because they lack crucial information about the stability of the snowpack. Annual avalanche fatalities have increased by 220% over the past two decades, fueled by a rapidly growing interest in backcountry sports, now the fastest growing segment of the snow sports industry. Moreover, avalanche risk is not limited to recreationalists, but affects the military, researchers, search and rescue personnel, transportation authorities, and alpine mining operations alike.

Current approaches to avalanche safety are reactive. Beacons, probes, shovels, and avalanche airbags are all designed to help increase chances of survival after you've been trapped in an avalanche. With a fatality rate greater than 50% for those buried in an avalanche, these devices fail to address the real need—avoiding avalanches altogether. Today's manual snow pit methods to detect weak layers in the snow under foot are highly error prone, time-consuming, subjective, and only provide information about conditions in one location. There is a significant need for a low-cost device that can increase the speed and accuracy with which snowpack profiles can be evaluated.

SUMMARY OF THE DISCLOSURE

In one aspect, the present disclosure is directed at an apparatus for measuring snow structure and stability. The apparatus can include a pole having a length, a first end and a second end; a sensing unit located at the first end of the pole, the sensing unit including a head shaped for probing a layer of snow, the sensing unit configured to sense a temperature of the layer of snow; and a range sensor configured to measure a distance between the range sensor and a surface of the layer of snow. The apparatus can also include a processor configured to determine a depth of penetration based on the distance measured by the range sensor and the length of the pole; and determine a profile of snow layer temperature according to depth based on the temperature sensed by the sensing unit.

In some embodiments, the apparatus can include an ambient temperature sensor configured to sense a local ambient temperature.

In some embodiments, the ambient temperature sensor of the apparatus can be integrated into the sensing unit.

In some embodiments, the apparatus can include a notification device configured to indicate to a user that a stable

2

temperature measurement has been taken and to direct the user to insert the sensing unit deeper into the layer of snow.

In some embodiments, the notification device can include at least one of a data display screen, a speaker, a light emitting diode (LED), and a haptic device.

In some embodiments, the apparatus can include a notification device configured to direct a user to stop inserting the sensing unit deeper into the layer of snow until a stable temperature measurement can be taken.

In some embodiments, the apparatus can include an optical sensor configured to measure a distance of displacement, and wherein the processor is configured to determine the depth of penetration based at least in part on the distance of displacement measured by the optical sensor.

In some embodiments, the apparatus can include an accelerometer, wherein the processor is configured to determine the depth of penetration based at least in part on an acceleration measured by the accelerometer.

In some embodiments, the apparatus can include a data display screen.

In some embodiments, the apparatus can include a wireless communication device configured to automatically determine the geographical position of the apparatus.

In some embodiments, the apparatus can include a wireless communication module for communicating with at least one of a wireless data network and a mobile device.

In some embodiments, the range sensor of the apparatus can be configured to measure distance by transmitting and receiving a beam of radiation.

In some embodiments, the range sensor of the apparatus can be configured to measure distance using sound waves.

In another aspect, the present disclosure is directed at a method for measuring snow structure and stability which can include: (a) sensing, at a probe that is being inserted progressively deeper into a snow layer, a temperature of the snow layer; (b) measuring a depth of penetration based on the distance measured by a range sensor; and (c) repeating steps (a)-(b) to determine a profile of snow layer temperature according to depth based on the sensed temperature and the measured depth of penetration.

In some embodiments, the method of the present disclosure can include determining to start a test based on at least one of a sensed resistance to penetration and input from an optical sensor; and determining to end the test when the measured depth of penetration decreases or remains constant for a predetermined period of time.

In some embodiments, the method of the present disclosure can include indicating to a user that a stable temperature measurement has been taken and directing the user to insert the probe deeper into the snow layer.

In some embodiments, the method of the present disclosure can indicate to the user that the stable temperature has been taken through at least one of a data display screen, a light-emitting diode (LED), and a haptic indicator.

In some embodiments, the method of the present disclosure can include directing a user to stop inserting the probe deeper into the snow layer until a stable temperature measurement can be taken.

In some embodiments, the method of the present disclosure can include measuring the depth of penetration is based at least in part on a displacement measured by an optical sensor.

BRIEF DESCRIPTION OF FIGURES

FIG. 1 is a diagram of an example snow-measurement device in its extended position, according to embodiments of the present disclosure.

3

FIG. 2A is an illustration of how an example snow-measurement device measures the depth of its tip beneath a snowpack using a range sensor, according to embodiments of the present disclosure.

FIG. 2B is a diagram of the tip of an example snow-measurement device incorporating an optional optical flow sensor and optical trigger, according to embodiments of the present disclosure.

FIG. 3A is a diagram depicting a cross-section view of the connection between an example snow-measurement device's handle and pole, according to embodiments of the present disclosure.

FIG. 3B is a diagram depicting the segments which comprise an example snow-measurement device's pole, according to embodiments of the present disclosure.

FIG. 3C is a close-up diagram depicting an example snow-measurement device in its collapsed position, according to embodiments of the present disclosure.

FIG. 4 is a diagram of the interface between the lower pole segment and the lower-mid pole segment of an example snow-measurement device, according to embodiments of the present disclosure.

FIG. 5 is a diagram of the locking mechanism incorporated into the top of an example snow-measurement device's pole and handle when the device is in its extended position, according to embodiments of the present disclosure.

FIG. 6 is a diagram of the locking mechanism incorporated into the top of an example snow-measurement device's pole and handle when the device is in its collapsed position, according to embodiments of the present disclosure.

FIG. 7 is a diagram of the tip of an example snow-measurement device incorporating a force sensor comprising a load cell diaphragm, according to embodiments of the present disclosure.

FIG. 8A is a diagram of the tip of an example snow-measurement device incorporating a force sensor comprising a load cell cylinder, according to embodiments of the present disclosure.

FIG. 8B is a diagram of the tip of an example snow-measurement device incorporating a force sensor comprising a pressure cavity and pressure sensor, according to embodiments of the present disclosure.

FIG. 8C is a diagram of the tip of an example snow-measurement device incorporating a hall effect sensor, a compression spring, and a magnetic upper end, according to embodiments of the present disclosure.

FIG. 9 is a diagram of the tip of an example snow-measurement device incorporating a weather o-ring, according to embodiments of the present disclosure.

FIG. 10 is a diagram of the tip of an example device incorporating a weather tubing, according to embodiments of the present disclosure.

FIG. 11 is a diagram of the tip of an example snow-measurement device incorporating a weather-proof filler, according to embodiments of the present disclosure.

FIG. 12A is a side view of the handle of an example snow-measurement device and its associated components, according to embodiments of the present disclosure.

FIG. 12B is a front view of the handle of an example snow-measurement device and its associated components, according to embodiments of the present disclosure.

FIG. 12C is an illustration of the difference between slope aspect and slope inclination, according to embodiments of the present disclosure.

FIG. 13 is a block diagram of an example snow-measurement device's electronic subsystems, according to embodiments of the present disclosure.

4

FIG. 14 is a flow-chart depicting the process for using an example snow-measurement device, according to embodiments of the present disclosure.

FIG. 15 is a diagram of an example snow-measurement device that uses an external mobile-device (e.g., a smart-phone) for a screen instead of including a display on the snow-measurement device itself, according to embodiments of the present disclosure.

FIG. 16 is a diagram of an example snow-measurement device that includes a mobile-device mount inside the handle, according to embodiments of the present disclosure.

FIG. 17 is a flow-chart depicting the data processing algorithms used by an example snow-measurement device to derive snow stratigraphy from raw penetration data, according to embodiments of the present disclosure.

FIG. 18 is an illustration of the data flow from an example snow-measurement device to an online database and to remotely located users, according to embodiments of the present disclosure.

FIG. 19 is an illustration of a user interface for an example mobile-device-based application to view data collected by a snow-measurement device, according to embodiments of the present disclosure.

DESCRIPTION

The system can introduce a portable handheld snowpack measurement tool (the "snow-measurement device" or "device") that helps users more quickly and accurately assess snowpack and other avalanche risk factors, helping them make informed travel decisions in avalanche terrain. The device can also be used for purposes unrelated to avalanches, such as hydrology and soil measurement, among others. Additionally, the system includes a way of sharing user and geographic specific information with other users via an online database. The physical device measures and saves snowpack information, which the user can then upload to the database for other users' benefit. In this way, the physical device crowd sources safety information across a broad network of users and integrates and tracks this data over time online. Finally, the system includes a data interpretation component, where aggregated data is analyzed to look for trends between individual data results and large-scale avalanche activity and changes in snow structure.

An example of a consumer use scenario for this product would be a backcountry skier who takes periodic measurements with the device while traveling up a mountain in avalanche terrain. The measurements she acquires on her journey up the mountain helps her understand the features of the snowpack, and inform her decision about where she feels it is safe or unsafe to travel in the terrain. The user is able to share information across device user interfaces, extract valuable data from external sources, and report localized conditions externally. With many datasets in the database, trends relating snow structure, location, terrain characteristics, avalanche risk, water resources, and weather patterns can be uncovered.

An example of a professional use scenario for this product would be a mountain guide, avalanche forecaster, ski patrolter, or scientist that takes frequent measurements with the device while in mountain terrain to better ensure the safety of their clients/resort, or for scientific and snow study purposes. With the ability to gather more information in real-time, view information from across the network, and track this information historically, avalanche professionals can not only be able to make better terrain management decisions, they can also be able to make better forecasts. In

5

a similar manner, hydrologists and snow scientists can be able to use this tool to gather stratigraphic and micro-structural snow data, and ultimately draw better conclusions about snow and water resources around the globe. Additionally, the oil sands industry can benefit from this apparatus by being able to quickly evaluate the hardness of surface oil layers to determine the sands' readiness for collection and further processing.

In one embodiment, the device can be a portable or hand held tool that allows the user to assess snowpack risks in real time while traveling in snowy terrain.

The device can use a snow penetration resistance sensor and a depth sensor for determining the depth of the snow penetration resistance sensor. The device also can include other subsystems necessary for recording and displaying how the snowpack's resistance to penetration varies with depth. This knowledge can contribute to identifying areas with avalanche potential.

Combined with additional sensor readings, such as, but not limited to, slope inclination, slope orientation, ambient temperature, temperature profile of a snow layer as a function of depth, snow grain size, snow grain size profile as a function of depth, wind, weather forecast, weather history, user weight, altitude, snow water content, layer energy, and geolocation, the device can give users a quick, easy-to-read data output of the snow features with unprecedented accuracy and ease of use, thereby improving backcountry information management and potentially safety.

FIG. 1 is a schematic view of an exemplary device in the extended position, according to some aspects of the present disclosure. In some embodiments, the device can include a one-meter or longer collapsible cylindrical pole **100** with a handle **102** on one end, and a snowpack resistance sensor **104** on the other end. Pole **100** can be made of aluminum, steel, titanium, carbon fiber, plastic, and/or other materials that can be made into tubing. Handle **102** can be made of rubber, metal, and/or plastic, or any other moldable, machinable, or otherwise formable material. Other snowpack measurement sensors (i.e. temperature) can also be incorporated into a tip **106** (tip **106** refers to the end of the probe and any snowpack measurement sensors located there, and snowpack resistance sensor **104** is said to be part of tip **106**). One or more sensors for determining the depth of tip **106** can be incorporated into the device (e.g., snow depth sensor **108** (see FIG. 2A), optical flow sensor **208** (see FIG. 2B)). Handle **102** serves as a place for the user to grab the device with their hand(s) and push the pole **100** through the snow to obtain a measurement. Additionally, handle **102** can contain embedded electronics, including, but not limited to: user interface buttons **110**, a display **112**, an accelerometer **118**, and an electronic circuit **114** necessary for collecting, processing, displaying, and transmitting data and snowpack measurements. Finally, a power supply **116** is embedded in the handle and provides power to electronic circuit **114** and snowpack measurement sensors **104** and snow depth sensor **108**, as well as any other sensors located in the device.

The device can optionally be equipped with a ski pole basket (not shown) at tip **106** to double as a ski or hiking pole. In this case, a cover can slide over tip **106** to prevent it from damage. Additionally, a collapsible extension can be added at tip **106** to increase the overall length so that the device can be used as an avalanche rescue probe in emergency situations.

FIG. 2A is a schematic illustration of how snow depth sensor **108** operates to measure the depth of tip **106**, according to some aspects of the present disclosure. The depth **200** of tip **106** is measured as the probe penetrates a snowpack

6

202. This is done by range-finding snow depth sensor **108**, which calculates the depth **200** (D) of the tip **106** by subtracting a distance **204** (X) to the snow surface from a pre-determined probe length **206** (L). Range-finding snow depth sensor **108** may comprise an infra-red (IR) range-finding device, a radio frequency (RF) range-finding device, or a range-finding device that operates by sending and receiving sound- or pressure-waves (e.g., an ultrasonic range sensor).

The pole diameter can be $\frac{3}{4}$ inches or less so that less force is required to push the probe through the snowpack. As device tip **106** enters snow layers of different hardness, a different amount of force is required to penetrate the different hardness layers. However, the variations in force required to penetrate the snowpack is reduced by choosing a small diameter pole, which can result in a penetration closer to constant speed. Because penetration resistance is somewhat dependent on penetration speed, better data can be recorded with a smaller diameter pole where penetration speed is near constant. If penetration resistance is dependent on speed, a lookup table can be used to adjust measured resistance based on the speed at which that resistance was measured. A lookup table for speed correction can be used because the speed of penetration can be calculated at any given point based on the rate of change of the depth **200**. The average speed between two depth readings taken close together can show a speed very close to tip's **106** actual speed through snowpack **202**.

FIG. 2B shows an alternative embodiment, where depth **200** of tip **106** is calculated using an optical flow sensor **208** (such as those found in any optical computer mouse) on tip **106**, according to some aspects of the present disclosure. Here, optical flow sensor **208** is mounted at tip **106** and oriented to look radially outward into snowpack **202**. This is possible because tip **106** slides through snowpack **202**, and optical flow sensor **208** can derive displacement based on the changing image it sees as it slides by the snow.

Additionally, an optical trigger **210** can be incorporated into tip **106** to detect the exact moment when tip **106** enters the snowpack **202**. If the optical flow sensor **208** is not incorporated, optical trigger **210** is useful for providing the device with an absolute reference for the beginning of the test. Optical trigger **210** may be a photoresistor.

Another embodiment uses both range-finding snow depth sensor **108** and optical flow sensor **208**. This is advantageous over using a single sensor because range-finding sensors suitable for snow depth sensor **108** show absolute depth with some error, and optical flow sensor **208** shows relative motion with some error. If necessary, more accurate movement of the device can be measured by having both an absolute depth sensor (such as snow depth sensor **108**) and a relative motion sensor (such as optical flow sensor **208**). Combining these technologies may also be useful if one sensor has a limited sample rate, because the other sensor can then be used to fill in information between samples taken at a limited rate.

Ultimately, incorporation of the above sensors can provide a depth measurement at a time interval dependent on the maximum sample rate of said depth measurement sensors. Infrared and ultrasonic sensors typically have sampling rates lower than snowpack resistance sensor **104**, requiring that depth values between depth measurement sensor readings be determined by interpolation. While linear interpolation is a good approximation if speed is near constant between depth measurement sensor readings, better results can be obtained if the interpolation incorporates data from accelerometer **118** to account for speed changes between

7

depth measurements. While accelerometer **118** is shown mounted in handle **102** in FIG. **1**, it is to be understood that the accelerometer may be mounted anywhere in the device, including pole **100** or tip **106**. Similarly, optical flow sensor **208** can provide information about these speed changes.

FIG. **3A** is a schematic cross-section view illustrating how handle **102** can connect to the top of cylindrical pole **100**, according to some aspects of the present disclosure. Drawn is one half of handle **102**. Handle **102** fits around cylindrical sliding tube **300**. A flanged stop **302** is press fit, glued, or welded into the sliding tube **300**, and the flange sits inside a flange groove **303** in handle **102** to prevent sliding tube **300** from sliding along its axis inside handle **102**. A cylindrical upper pole segment **304** fits inside sliding tube **300** to form a sliding fit. A multi-conductor tether **306** runs inside a hole through the axis of flanged stop **302**. An upper tether collar **308** is fixed onto the tether **306** with tether collar set screws **310**, preventing tether **306** from sliding inside upper tether collar **308**. Upper tether collar **308** sits inside a collar groove **309** in handle **102**, which anchors both upper tether collar **308** and tether **306** in handle **102**.

FIG. **3B** is a schematic illustration showing the collapsed device folded into approximately one quarter of the full, extended length, according to some aspects of the present disclosure. Continuing away from handle **102** (see above, FIG. **3A**) and towards tip **106**, tether **306** runs through upper pole segment **304**, and then through an upper-mid pole segment **311**, a lower-mid pole segment **312**, and a lower pole segment **314**. The tether terminates at tip **106**, where it is electrically connected to any snowpack measurement sensors in the tip **106**, creating an electrical and mechanical connection between handle **102** and tip **106**. At interfaces between pole segments there is a ferrule **316** and a ferrule cone **318** on one pole segment and a ferrule socket **320** on the other pole segment. A lower tether collar **322** is fixed inside lower pole segment **314** with epoxy, glue, or a weld, or by means of a press fit between the outside diameter of lower tether collar **322** and the inside diameter of lower pole segment **314**. Lower tether collar **322** is fixed onto tether **306** with tether collar set screws **310**, preventing tether **306** from sliding inside lower tether collar **322**. Tip **106** is attached to the lower end of lower pole segment **314** by means of a press fit or threaded connection.

The sliding interface between sliding tube **300** and upper pole segment **304** allows the motion necessary to collapse and extend the probe in the following manner. When the device is in the collapsed position as shown in FIG. **3B**, the user can place one hand on handle **102**, and the other on upper pole segment **304**, and slide them away from each other. This motion removes the slack in tether **306** between pole segments, causing ferrule cone **318** to guide ferrule **316** into ferrule socket **320**. When the motion is complete, each ferrule cone **318** and ferrule **316** sits inside the ferrule socket **320**, forming a connection between pole segments in a similar manner as many collapsible tent poles and avalanche rescue probes. When the user wishes to collapse the device, they must simply slide handle **102** and upper pole segment **304** towards each other, which returns the slack in tether **306** between the pole segments, allowing the user to fold the device at the exposed sections of flexible tether **306**. Tether **306** helps contain the collapsed device as a single unit, easing storage and handling of the collapsed device.

The components shown in FIG. **3A** and FIG. **3B** can be made of, but not limited to, plastic, aluminum, steel, stainless steel, and titanium. In embodiments where pole **100** is electrically conductive, an electrical ground can be connected to upper pole segment **304** such that the ground

8

continues all the way to tip **106**. This helps shield tether **306** from external sources of electrical noise. Additionally, the electromechanical contacts created when pole **100** is extended can be used as a switch to turn the device on.

FIG. **3C** shows an exemplary embodiment for bundling the device together in the collapsed position for ease of transport and storage. An elastic strap **324** at the bottom of the handle **102** can be wrapped around the pole bundle **326** to contain them and keep the entire collapsed unit together.

FIG. **4** is a close-up view of the interface between lower pole segment **314** and lower-mid pole segment **312**, according to some aspects of the present disclosure. Ferrule **316** provides a tether anchor mechanical stop **400** for lower tether collar **322**. As described above, the glue/weld/press-fit connection between lower tether collar **322** and lower pole segment **314** prevents the lower tether collar from sliding towards the tip due to force transmitted by compression of tether **306**, which can be small compared to force pulling lower tether collar **322** away from the tip due to the tension force in tether **306**. Instead of designing the glue/weld/press-fit connection to tolerate this large tension force, the glue/weld/press-fit between ferrule **316** and lower pole segment **314** can be used, where the lower end of the ferrule functions as a tether anchor mechanical stop **400**. Curved tether interfaces **402** are shown on ferrule cone **318**, which help prevent abrasion and wear on the tether at these sliding and bending interfaces.

FIG. **5** shows a feature for locking the sliding mechanism described above so that the device remains extended or collapsed throughout use, according to some aspects of the present disclosure. In some embodiments, a spring plug **506** can be attached inside the upper end of the upper pole segment **304** by press-fit, adhesive, or a weld. A spring plug flat **508** is a feature on spring plug **506** that accommodates a spring arm **504**, which is fixed in place by press-fit, adhesive, or a weld. At the lower end of the spring arm **504** is a spring button **500**, attached by adhesive, nut and bolt, or a weld. This secures the assembly of spring plug **506**, spring arm **504**, spring button **500**, and upper pole segment **304** such that the center of spring button **500** is located at the center of a spring button hole **502** on upper pole segment **304**. The spring arm is held in place at the interface between spring plug **506** and upper pole segment **304**. Finally, a locking indent group **510** is a feature in the sliding tube **300** $\frac{1}{2}$ inch or less below the lower face of flanged stop **302**.

At the end of the sliding motion to extend the device, sliding tube **300** clears the spring button **500** at the end of the sliding motion, allowing spring button **500** to pop through spring button hole **502**. This is possible because spring arm **504** is pre-bent to cause it to exert a radially outward force on spring button **500**. The user is then only able to collapse the device if he pushes the spring button **500** in while sliding the handle **102** towards upper pole segment **304**. Without this locking mechanism, handle **102** and top pole segment **304** could slide towards each other while the user pushes the device into the snowpack, resulting in the device's collapse and making data collection difficult. Because of the cold-weather use case of this invention, the spring button should be large enough to use with gloved hands ($\frac{3}{16}$ inch or greater diameter).

As mentioned above, to collapse the device, the user pushes in spring button **500** and then slides handle **102** and upper pole segment **304** towards each other. Sliding tube **300** then slides over spring button **500**, thereby disengaging the locking mechanism. When the collapsing sliding motion is complete, locking indent group **510** squeezes the upper part of upper pole segment **304**, resulting in enough friction to

lock the device in the collapsed position. This is convenient because it maintains the collapsed position while the user folds the device at the sections of exposed tether **306** and transports the device between test locations.

Spring arm **504** can be made of an elastic material such as spring steel, and an exemplary material for spring button **500** is stainless steel. Exemplary materials for the other parts introduced in FIG. **5** are high strength aluminum or steel, chosen for machinability, strength, corrosion resistance, moderate cost, and high strength to weight ratio.

FIG. **6** is a close-up schematic view of the sliding/locking mechanism while collapsed, according to some aspects of the present disclosure. Here, sliding tube **300** covers spring button **500**, and locking indent group **510** maintains the mechanism's collapsed configuration during user handling and transport.

The locking spring button mechanism described above is preferred over traditional spring buttons because it creates enough clearance inside upper pole segment **304** to accommodate tether **306**. Additionally, the way spring arm **504** is anchored at the upper part of upper pole segment **304** is an easier assembly process than anchoring spring arm **504** at the location of spring button hole **502**. The collapsing mechanism described above requires three inches or more of sliding motion so that there is enough slack to slip pole segments out of each ferrule **316**, and the length of spring arm **504** can easily be adjusted to meet this specification. More traditional spring buttons don't allow this flexibility in location, or provide enough clearance for tether **306** in such a small diameter tube.

FIG. **7** shows tip **106** and its associated components, according to some aspects of the present disclosure. Lower pole segment **314** connects to a plastic, rubber, metal, or composite damping connector **700** by press fit, threads, adhesive, or a weld. A snowpack temperature sensor **702** or other snowpack measurement sensor can be incorporated into the damping connector **700**. Onto the lower portion of damping connector **700** is connected a tip pole segment **704**, which is connected by press fit, threads, adhesive, or a weld. Tip pole segment **704** connects to a tip connector **706** by press fit, threads, adhesive, or a weld. Tip connector **706** is also a suitable location for temperature sensor **702** or other snowpack measurement sensors. In the lower portion of tip connector **706** is a load cell cavity **728**. A load cell diaphragm **708** is fixed inside the rim of load cell cavity **728** by press fit, adhesive, or a weld such that it covers the lower end of load cell cavity **728**. Onto one of the faces of load cell diaphragm **708** one or more strain gauges **710** are mounted. A tip sheath **712** fixes over the end of tip connector **706** by press fit, adhesive, threads, or a weld. A tip cone **714** fixes into the other end of tip sheath **712**. A tip cylinder **716** can be a cylindrical hole running through the center axis of the tip cone **714**. A resistance sensing element **718** can be a cylindrical shaft that ends in a conical tip **719**. Slightly above conical tip **719** the diameter of the resistance sensing element **718** can be reduced to create an overload bumper **720**. The resistance-sensing element **718** continues as a cylindrical shaft that slip-fits inside the tip cylinder **716**. The upper end of the resistance-sensing element **718** can attach to the load cell diaphragm **708** by press fit, weld, adhesive, or threads. They could also be machined out of the same piece of stock, or 3D printed/laser sintered. Force sensors can be strain gauge or piezoelectric based force transducers.

When the device is pushed through the snowpack, varying amounts of resistance from different snow layers apply a force on conical tip **719**. This force is transmitted through resistance-sensing element **718** and onto load cell diaphragm

708. This force strains load cell diaphragm **708**, resulting in elongation or compression of strain gauges **710**. This strain causes a change in the electronic signal leaving strain gauges **710** that flows through load cell wires **726**. Load cell wires **726** travel through load cell cavity **728**, and then through a tip connector hole **730**. They can then emerge into a damping cavity **732** before passing into a damping connector hole **734**. Any wires from the snowpack temperature sensor **702** or other snowpack measurement sensors mounted in the damping connector **700** also travel through the damping connector **700** and enter the inside of lower pole segment **304**. Here, all wires associated with tip **106** can connect to tether **306**, resulting in an electrical connection between handle **102** and sensors in tip **106**.

A cone internal angle **736** of tip cone **714** and a tip internal angle **738** of conical tip **719** can be 60 degrees or less to decrease the magnitude of resistance caused by a given snow layer. This is possible because penetration resistance decreases as the internal angle of a cone penetrometer tip decreases. This can make it easier for the user to penetrate the snowpack where hard layers are present, as well as minimize variations in penetration speed caused by the varying hardness encountered by tip **106**. The cone internal angle **736** can be further decreased below 60 degrees to prevent tip cone **714** from compressing the snow in front of it.

Resistance sensing element **718** and other components between the snow and strain gauges **710** can be lightweight to minimize inertial forces sensed by the snowpack resistance sensor **104**. Minimizing this mass can also reduce the resonant frequency of the force sensing system and therefore allow for a higher sampling rate and snowpack measurement resolution. Because robustness is also important for resistance sensing **718** element, high strength aluminum, titanium, or stainless steel are possible materials. The maximum diameter of conical tip **719** affects the minimum layer thickness that can be measured by the device. If the internal angle of the conical tip **719** is small, or if the maximum diameter of the conical tip **719** is large, the thickness of snow affecting the snowpack resistance sensor increases. Some diameter should be chosen based on minimum desired layer resolution. For avalanche safety uses, the device uses a conical tip **719** diameter of 0.3125 inches or less. This diameter should not be completely minimized (below 0.1 inches for instance), because small local variations in the snowpack can be expressed if the diameter is on the order of such variations. In case local variations do affect test results, the device includes a way of probing several times in the same location and averaging the results to produce a more representative snow profile.

A tip offset distance **740** can be set to bring conical tip **719** out in front of the lower face of tip cone **714**. This design can help the device maintain a constant speed through snow layer interfaces. Because conical tip **714**'s and pole **100**'s cross-sectional areas are several times larger than the cross-sectional area of resistance sensing element **718**, the majority of the resistance is provided not by the resistance sensing element **718**, but instead by the overall pole diameter. As a user pushes the device through the snowpack, changes in resistance due to different snow layers can make it difficult for the user to penetrate at constant speed. For instance, as the device breaks through a hard layer and enters soft snow, acceleration occurs. It may be beneficial to measure the transition from one layer to the next at a constant speed instead of while accelerating. If the tip offset distance **740** is greater than zero, conical tip **719** can enter the next layer while tip cone **714** is still in the other layer above it. This

11

allows tip cone **714** to help regulate penetration speed while conical tip **719** senses ahead of tip cone **714** so that it can measure layer transitions at near constant speed.

Damping connector **700** is an optional feature that can be incorporated to isolate tip **106** from any vibrations in the other parts of the device. When not incorporated, lower pole segment **314** can connect directly to tip connector **706** by press fit, adhesive, threads, or a weld, eliminating the need for damping connector **704**. Any snowpack measurement sensors embedded in damping connector **700** could then be embedded in tip connector **706** instead. Additionally, tip connector **706** can be made of rubber, composite, plastic, or another material with damping characteristics to help isolate the lower parts of tip **106** from vibrations in the upper device.

FIG. **8A** shows an alternative embodiment for the force sensing mechanism described in FIG. **7**. Damping connector **700** is not shown in this figure. Instead of load cell diaphragm **708**, a load cell cylinder **800** connects to a cylinder force transmitter **802**, which then connects to resistance-sensing element **718**. Strain gauges **710** can be mounted on the exterior surface of load cell cylinder **800**, or cast inside load cell cylinder **800**.

The resistance from the snowpack results in a force on the resistance-sensing element **718**, which can act to compress load cell cylinder **800** along an axis parallel to lower pole segment **314** and expand/elongate load cell cylinder **800** along an axis perpendicular to lower pole segment **314**. This results in a change in the electronic signal leaving strain gauges **710**.

The overload bumper **720** can prevent the resistance-sensing element **718** from displacing so much that it damages more delicate parts above it, such as the load cell cylinder **800** or load cell diaphragm **708**. These delicate components measure force because of elastic deformation, and if force continues into the plastic deformation regime, the device's force sensing mechanism can break and need replacement. To prevent this from happening, tip **106** is designed such that resistance-sensing element **718** can receive much more force than would normally damage these parts. When a certain force is applied to the resistance-sensing element **718**, overload bumper **720** contacts tip cone **714** and prevents any further displacement that could damage components inside tip **106**. The exact force and displacement at which overload bumper **720** engages tip cone **714** can be tuned by rotating the resistance-sensing element and changing how far onto load cell diaphragm/cylinder force transmitter **708/802** it threads. Doing this changes the zero-load distance between overload bumper **720** and tip cone **714**. Finally, changing the stiffness of load cell diaphragm **708** or load cell cylinder **800** can determine the force in the system when overload bumper **720** contacts tip cone **714**. Most OEM load cells experience very little displacement (0.003 inches or less) at maximum load, requiring that this displacement adjustment be equally subtle. Such tolerances are expensive and difficult to achieve in multi-part assemblies like this one. To simplify this matter, load cell diaphragm **708** can be a specific material and geometry such that it experiences more displacement at maximum load without yielding (i.e. a material that yields at higher strain). For instance, a spring steel or plastic diaphragm of the right thickness can result in maximum load displacements of 0.025 inches or more. This can ease the tolerances required to protect tip **106** from overloading, because the zero load displacement can then be on the order of 0.025 inches (or less) instead of 0.003 inches. Additionally, if resistance sensing element **718** threads into the load cell diaphragm/

12

cylinder force transmitter **708/802**, simply twisting it changes the zero-load distance between overload bumper **720** and tip cone **714**, which allows post-assembly fine-tuning of the force at which overload protection engages. Additionally, the threading allows resistance-sensing element **718** to be completely removed from the device, a convenient feature if the tip needs cleaning, replacement, or other maintenance.

If additional displacement is needed to achieve overload protection, a spring can be added in series anywhere between where the snow contacts the conical tip **719** and where the force sensor attaches to the mechanical ground of the tip **106** (i.e. the tip connector **706**). This can give the sensor assembly compliance at the expense of reducing its resonant frequency. A possible embodiment of this concept is shown in FIG. **8A**, according to some aspects of the present disclosure, where the resistance sensing element **718** includes a compliant flexure **803**. This reduces the stiffness of the mechanism that carries snowpack resistance to the force sensor, therefore resulting in larger displacements for a given applied force. Compliant flexure **803** could be substituted for a compression spring for the same result.

FIG. **8B** shows an alternative embodiment for the snowpack resistance sensor **104**, according to some aspects of the present disclosure. Here, resistance sensing element **718** has a blunted upper end **804** that ends inside a pressure cavity **806** between tip cone **714** and tip connector **706**. Force from the snow results in an increase in pressure inside pressure cavity **806**, and this change in pressure is measured by a pressure sensor **808**.

Pressure cavity **806** can be filled with anything that exhibits viscous or visco-elastic behavior such as a polymer, oil, or gel. Polymers and gels have an advantage over a liquid because they hold their shape, requiring no need for a fluid seal to prevent it from leaking out of the pressure cavity **806**. However, liquid has the advantage that it has zero shear modulus, so the weather-proofing seal described in FIG. **11** (below) can be used to prevent liquid from leaking. A seal can also be created by use of a metal bellows or a sealing diaphragm **809** connected to the end of the outside diameter of the resistance sensing element **718** and the inside diameter of the tip cylinder **716** or inside diameter of the pressure cavity **806**. This sealing diaphragm should be thin (and therefore compliant) enough to allow enough displacement to adequately pressurize pressure cavity **806** from typical snowpack resistance pressures (approximately 0-3 MPa).

FIG. **8C** shows another embodiment for snowpack resistance sensor **104**, where a hall effect sensor **810** and a compression spring **814** are used together to create a force sensor, according to some aspects of the present disclosure. Here, resistance sensing element **718** can have a magnetic upper end **812**. Compression spring **814** can be in parallel with the hall effect sensor **810** (mounted onto tip connector **706**) and the magnetic upper end **812**. Force from the snowpack can compress compression spring **814**, which reduces sensed displacement **816** (S) between magnetic upper end **812** and the hall effect sensor **810**. Hall effect sensor **810** can measure sensed displacement **816** because the motion of the magnetic upper end **812** changes the magnetic field measured by hall effect sensor **810**. Similarly, other displacement sensor in parallel with a spring could be used to create a force sensor. Possible other displacement sensors include a linear variable differential transformer (LVDT), a capacitance sensor, or a position sensitive diode. Additionally, instead of axial compression spring **814** shown

13

in FIG. 8C, a cantilever or diaphragm can be used to create a spring between the target (in this case, resistance sensing element 718) and the sensor.

FIG. 9 shows a way of sealing the tip 106 with a weather o-ring 900, according to some aspects of the present disclosure. Weather sealing is important because it can prevent water, snow, ice, and other debris from entering the assembly and adding friction between resistance-sensing element 718 and tip cylinder 716. The electronics in the tip (i.e. strain gauges 710) should also be protected from contaminants. Weather o-ring 900 sits between overload bumper 720 and the lower surface of tip cone 714. Weather o-ring 900 should not be pre-loaded by resistance-sensing element 718, because this would make any forces smaller than the pre-load force immeasurable by the device (the preloading re-directs force away from the force sensor and into tip sheath 712).

FIG. 10 shows an alternative embodiment for weather sealing that uses a piece of tubing (weather tubing 1000) instead of weather o-ring 900, according to some aspects of the present disclosure. Weather tubing 1000 rests between overload bumper 720 and lower surface of tip cone 714. To accommodate the thickness of weather tubing 1000, grooves 1002 and 1004 are cut out of resistance-sensing element 718 and tip cone 714, respectively.

FIG. 11 shows another embodiment for weather sealing tip 106, where weather sealing is done with a filler 1100 approach, according to some aspects of the present disclosure. Filler 1100 fills the space between tip cylinder 716 and resistance-sensing element 718. Fixture grooves 1102 can be added to the inside of tip cylinder 716 to prevent the filler from slipping inside tip cylinder 716. Alternatively (or in addition), internal threads on tip cylinder 716 could be added, as well as external threads on resistance sensing element 718. Resistance sensing element 718 and filler 1100 do not slide relative to one another, but the filler 1100 is able to deform and allow displacement of resistance sensing element 718 necessary for transmitting force to the load cell above it. Filler 1100 can be a cast polymer, allowing it to fill the void space as a liquid before curing into a soft, deformable solid. Silicone polymers may be suitable because their properties are less sensitive to temperature changes than many other polymers.

A similar seal can also be created by placing o-rings or annular pieces of a soft rubber between resistance sensing element 718 and tip cylinder 716 (as opposed to pouring polymer to incorporate the rubber seal).

FIG. 12A shows handle 102 and its associated components, according to some aspects of the present disclosure. Inside handle 102 is a microcontroller 1200, a memory subsystem 1222, a snowpack measurement subsystem 1224, an environmental measurement subsystem 1202 which may include some or all of the following: a GPS block 1212, inclinometer (not shown), a tilt-compensated compass 1215, ambient temperature sensor (not shown), altimeter (not shown), and humidity sensor (not shown), and an external communication subsystem 1204 containing some or all of the following: USB port (not shown), WiFi module (not shown), and Bluetooth module (not shown). Display 112 can be visible on the exterior of handle 102. A user interface light emitting diode (UI LED) 1208 is also visible to the user as she holds the device by a grip 1210 (or alternatively, a UI tone can be audible to the user). Buttons 110 are accessible by the user when she is holding the grip 1210. Handle 102 also can include power supply 116, range-finding snow depth sensor 108, sliding tube 300, flanged stop 302, upper tether collar 308, and upper end of the tether 306.

14

Handle 102 serves as a place for the user to hold the device, as well as housing for the electronics that aren't located in tip 106. A GPS block 1212 in handle 102 automatically stores the location of each test. The user can link each test to the slope's inclination by holding the device parallel to the slope and holding the inclinometer button before the test start button is pressed. Similarly, the user can face downslope and hold the aspect button to store that aspect with the subsequent test. If neither of these measurements are taken before a test, the test can simply lack aspect and inclination information.

Each of buttons 110 should be large enough to press with a gloved hand, and a watertight gasket can be placed around each button to prevent water and other contaminants from entering handle 110.

Note that UI LED 1208 can be replaced or combined with a UI tone, such that the information is conveyed as an auditory signal.

FIG. 12B is a schematic illustration of handle 102 and associated user interface, according to some aspects of the present disclosure. The user interface is managed by microcontroller 1200, which communicates to the user via display 112 and UI LED 1208. The user is then able to navigate user interface 1214 by pressing buttons 110. Buttons 110 enable the user to start a test, look at prior test results, power the device on/off, and view other information managed by the microcontroller.

Handle 102 can be made of two or more main pieces, and a handle parting line 1216 between them can be seen in FIG. 12B. Each piece comes together around sliding tube 300 to contain it, and parting line 1216 makes assembly possible while ensuring that sliding tube 300 cannot leave the handle once the two handle halves are fixed together with glue, screws, snap-fit, ultra-sonic weld, or other means.

FIG. 12C shows how the incorporation of a tilt-compensated compass 1215 can be used to measure slope aspect 1218 (i.e., which direction the slope is facing) and inclination 1220 in the same step, according to some aspects of the present disclosure. The slope aspect and inclination can be collected simultaneously by laying the probe on the snowpack facing directly uphill and holding a button to initiate data collection, and releasing it when the measurements have been taken. This is possible because the tilt-compensated compass 1215 (see FIG. 12A) can make an accurate compass reading even when the device is not parallel to the ground. In addition to bearing, the tilt-compensated compass 1215 records pitch and roll, which can be used to derive inclination.

FIG. 13 is a block diagram of an embodiment of the device's electronics, according to some aspects of the present disclosure. Microcontroller 1200 is connected to the user interface 1214, an external communications subsystem 1204, a memory subsystem 1222, an environmental measurement subsystem 1202, and a snowpack measurement subsystem 1224.

Microcontroller 1200 can pull data from memory subsystem 1222 and transmit it to a mobile device (e.g., a smartphone or tablet), computer, or associated web database via external communications subsystem 1204. This is possible because of WiFi, Bluetooth, and USB port modules embedded in handle 102. Memory subsystem 1222 can be any digital storage system, such as an SD card, micro SD card, hard drive, or other system.

Microcontroller 1200 can also record and show environmental data via user interface 1214 by reading the outputs of the device's environmental measurement sensors in its snowpack measurements subsystem 1224, which may

15

include components such as, but not limited to: a humidity sensor, an altimeter, a GPS block, an ambient temperature sensor, an inclinometer, and tilt-compensated compass. Snowpack measurements subsystem **1224** may also be responsible for managing the functions of snowpack resistance sensor **104**, snowpack temperature sensor **702**, snow depth sensor **108**, and a snow grain type or grain size sensor (not shown). Unlike the snowpack temperature sensor **702**, the ambient temperature sensor discussed above is configured to measure the temperature of the local ambient atmosphere and not the temperature of the snow layer. However, the functions of the ambient temperature sensor may also be performed by snowpack temperature sensor **702**.

FIG. **14** is a flow chart of the steps to use the device, according to some aspects of the present disclosure. The user can first unfold the device **1400** and slide the sliding tube **300** to lock the pole in extended position. Holding the power button to power on **1402** the device can be done before or after unfolding the device. Once powered, the user interface is used to initiate measurements **1406** via the environmental/snowpack measurement subsystem, or to view past measurements **1408** that are stored in the device's memory subsystem. Via the user interface, users can optionally have the device record environmental measurements **1410** such as, but not limited to, GPS location, temperature, relative humidity, inclination, and slope aspect. The user can also push the device tip through the snowpack **1412** to record snowpack measurements **1414**. The microcontroller receives the user's request through button inputs, and then directs the environmental/snowpack measurement subsystem to sample from their associated sensors. This data is stored in the device's memory subsystem. From there, the microcontroller processes the data in step **1418** as described by FIG. **17** and presents the processed data to the user via the display, which is part of the user interface. The user can interpret the data and press one of the buttons to queue that test to be shared **1420** with another device that connects to the device via its external communication subsystem (it is also possible for the user to set the device to automatically queue every test for upload). The user can repeat these steps as many times as they wish, and then collapse and power off the device by holding one of the buttons. Powering off **1422** is done by holding the power button. The device can be collapsed **1424** by pushing the spring button and sliding the sliding tube into the handle. An automatic power-off can occur if none of the buttons are pressed for one minute (the user can adjust this time setting). Test results may be transmitted to a user's mobile device (e.g., a smartphone or tablet). Test results can include any measurement taken by the device, including, without limitation, a profile of snow hardness as a function of depth, a profile of snow temperature as a function of depth, a profile of grain size as a function of depth, local ambient temperature, humidity, slope aspect, or inclination. A mobile device may include a display screen, a memory, a short-range communication module for sending and receiving data over a short-range wireless link (e.g., Bluetooth, WiFi, or NFC) or over a wired connection, and a long-range communication module configured to communicate with a central server via a wireless network. Test results may also be transferred to a user's personal computer, which also may include a display, a memory, a processor, and a short-range communication device. Once the user establishes a wireless or wired connection in step **1426** with their mobile device or computer, any test queued to transfer can automatically be shared with connected devices in step **1428** and can then be viewed on the external device in step **1430** (even if the connection is

16

subsequently broken). Next, any shared data can then be uploaded to an online database in step **1432** for further data analysis, mapping, and interpretation. The exact remaining steps to transfer information to the database (and the database's features) are described in a later section.

In addition to the steps outlined above, the user has the option to measure the snowpack temperature profile in a separate or concurrent step. While a fast-acting snowpack temperature sensor **702** could be incorporated into tip **106** such that the temperature profile is recorded at the same time as the hardness profile, an embodiment of the device can measure temperature in a different step. The user holds one of buttons **110** to enter snowpack temperature measurement mode, and display **106** can direct them to put tip **106** just beneath the snowpack surface **204**. When the slow-acting snowpack temperature sensor **702** has acquired a temperature measurement, the device may direct the user to slowly penetrate several centimeters using any of an indicator on display **106**, an audible tone from a speaker integrated into the device, a sequence of flashes from UI LED **1208**, a haptic device configured to vibrate the handle **102**, or any other notifications means known in the art. Once the user has reached new depth **200**, display **106**, an audible tone from the speaker, a sequence of flashes from UI LED **1208**, a vibration from the haptic device and/or some other notification means can signal the user to stop until a stable temperature measurement has been taken. This process can repeat until the user has pushed the pole **100** as far as possible through the snowpack. The temperature profile can then be graphed on the display **106** and interpreted by the user.

In addition to the steps outlined above, the user has the option to measure the snow grain size of the layers of the snowpack in a separate or concurrent step. A small camera and light source can be incorporated into the tip **106** that records images of the snow surface as the device penetrates the snowpack. The user can then view these images, along with the depth at which they were taken to see how the snow grains change throughout the snowpack. Another possible way of determining grain size is to use information from the snowpack resistance sensor, where an adequately high sample rate (at least 5 samples per mm) will show changes in the snowpack's resistance to penetration resulting from the loading and rupture of individual bonds between snow grains (Schneebeli, M., C. Pielmeier, and J. Johnson. "Measuring Snow Microstructure and Hardness Using a High Resolution Penetrometer." *Cold Regions Science and Technology*. 30.1-3 (1999): 101-114.).

FIG. **15** shows an embodiment where an external mobile device (e.g., a smartphone) **1502** can be used for the screen instead of including display **106** on the device itself, according to some aspects of the present disclosure. The mobile device **1502** may be similar to the mobile device described above in relation to FIG. **14**. Handle **102** still contains a microcontroller based data acquisition, signal processing, and external communications subsystem **1204**, and external communications modules such as Bluetooth or WiFi modules **1504** are used to send mobile device **1502** information to be displayed. The user is able to control the information on a mobile device display **1506** by pressing buttons **110** on the handle, or buttons integrated into the mobile device application **1508**.

FIG. **16** shows an alternative embodiment with a mobile-device mount located inside handle **102**, according to some aspects of the present disclosure. A mobile device housing **1600** covers the mobile device with a mobile device-viewing window **1608**, and provides a mobile device clamp **1604** to

17

hold mobile device **1502** in place. The microcontroller based data acquisition, signal processing, and external communications subsystem **1204** can wirelessly communicate with mobile device **1502**, or connect directly via mobile device connector **1602**. Mobile device-viewing window **1608** opens at window hinge **1606**, allowing the user to place her mobile device **1502** in mobile device housing **1600**. The user can operate the device and navigate the mobile device user interface by pressing buttons **110** on handle **102**. UI LED **1208** can provide a way of notifying the user of a test in progress (and other states of the device) that doesn't require looking at mobile device display **1506**.

These two embodiments that use a mobile device **1502** reduce the cost and size of the device. Mobile device **1502** can also be charged via the mobile device connector **1602**.

FIG. **17** is an overview of data processing algorithm used to show snow stratigraphy from raw penetration resistance data, according to some aspects of the present disclosure. A version of the raw test data **1700** can be saved to the device's memory subsystem **1222**. The raw data can be plotted to display **112** as penetration resistance vs. time as shown by **1701** in FIG. **17**. To derive penetration resistance with respect to depth rather than time from the raw test data **1700**, the first step can be for the microcontroller **1200** to process and filter **1702** the data with averaging, median filters, and exponential smoothing. Next, the microcontroller **1200** can identify the test start **1704** by the test start trigger from the snowpack resistance sensor **104**. If either optical trigger **210** or optical flow sensor **208** are present on the device, they can also be used to detect the exact moment when the device penetrates the snowpack, and so identify the test start **1704**. All data points collected before the test start **1704** can be discarded so that the start coincides with a depth equal to zero. Next, the depth rate of change **1706** can be calculated by looking at the relative change between each successive depth reading. The test end **1708** can be identified because it coincides with the last collected data point that shows depth was still increasing. Alternatively, the test end **1708** can be identified if the rate of change between each successive depth reading is below a certain threshold for a predetermined period of time, i.e., the device has stopped moving. From here, any data points where the depth rate of change **1706** shows that the tip **106** was moving out of the snowpack and not deeper than the previous point can be discarded **1708**. At this point, the data can be saved as a new version.

Considering the sampling rate and depth rate of change **1706** allows for the calculation of average penetration speed between depth measurements. This calculated penetration speed can be used to correct each penetration resistance value for penetration resistance's dependence on penetration speed by using a lookup table developed experimentally. This version of speed-corrected snowpack penetration resistance vs. depth **1712** can be saved to the memory subsystem **1222**, and plotted to the display **112** as trimmed and calibrated data **1713**.

Next, the speed-corrected snowpack data **1712** can be filtered for easier visual interpretation. In order to display snowpack penetration resistance vs. depth data in a way widely accepted by the avalanche safety community, steps can be taken to show more discrete layers than seen in the trimmed and calibrated data **1713**. Penetration resistance values that are within approximately 10% of each other can be averaged to filter out the subtle, yet unimportant variations detected by the snowpack resistance sensor **104** (averaging shown as step **1714** in FIG. **17**). Any large change in snowpack resistance can be greater than this 10% window, and hence significant hardness transitions can be preserved.

18

After this averaging is complete, the resistance values can be compared to the standard hand-hardness values accepted by the avalanche safety community by use of a lookup table (shown as step **1716** in FIG. **17**). The lookup table can be generated by experimentally collecting penetration resistance and hand-hardness data side by side. Finally, areas where the hardness decreases beyond a predetermined percentage (e.g., 50%) within a predetermined range (e.g., 10 cm) can be tagged as an area of concern **1720** (i.e., indicative of high avalanche risk). Users can have the option to adjust these parameters, including both the predetermined percentage and the predetermined range, based on their preferences. The smoothed data can then be plotted to the display **112** as shown in **1719**. The trimmed and calibrated data **1713** and smoothed data **1719** can be superimposed and displayed simultaneously if desired. Smoothed data **1719** therefore constitutes a profile of snow hardness as a function of depth.

In addition to the data processing outlined above, a correlation analysis can be done to show how closely a given test resembles one of the 10 snow hardness (resistance) profiles developed by Schweizer and Lutschg in Switzerland (Schweizer, J. and M. Lutschg. 2000. Measurements of human-triggered avalanches from the Swiss Alps. Proceedings International, Snow Science Workshop, Big Sky, Mont., U.S.A., 2-6 Oct. 2000). This can help the user understand the snow packs he measures, because comparison to these well understood ten profiles allows the user to benefit from the extensive studies performed by Schweizer and Lutschg. As new snow profile data is collected, these ten profiles can be re-developed, and new profiles can be added to this correlation test.

While the data processing steps discussed above with regard to FIG. **17** relate to measuring snow stratigraphy, they can also be applied to measuring a profile of snow layer temperature according to depth, and snow grain size according to depth. For example, the start of tests directed at measuring a profile of temperature and depth may be triggered by resistance sensed by snowpack resistance sensor **104**, optical trigger **210** or optical flow sensor **208**. Similarly, the end of such tests may also be identified as coinciding with the last collected data point that shows depth still increasing. Raw temperature and grain size data can also be smoothed, filtered and averaged in the manner described above, as well as compared with experimental values as described above. Finally, areas in the temperature and grain size data indicative of an increased avalanche risk can be tagged as an area of concern, potentially using the same or similar algorithms as described above.

In addition to the hardware device, this disclosure relates to a unique data sharing system to further enhance back-country safety and avalanche forecasting. Each time measurements are taken with the hardware device, the data is recorded both on the device and automatically shared via Bluetooth and WiFi to a mobile-device application (or other electronic communication device). Data includes a snow profile, slope inclination, slope orientation, time, GPS coordinates, temperature gradient, and more. The device and mobile device application also pull in external data on local weather, recent snowfall, etc. Additional computer software allows users to view data and move data to and from the hardware device.

Data transported to the mobile device application or computer software from the hardware device is stored on a server where it can be accessed remotely by a computer or other mobile device devices. Subscribers to the data services can be able to see all of the data acquired from users of the hardware device in real-time and historically. Sharing this

data across a broad network has the potential to create one of the largest sets of information on critical avalanche risk metrics in the world. With an innovative mobile device application and web portal that allow users to access local, regional, and global data, this information can improve decision making of individual backcountry adventurers as well as forecasting methods of ski resorts, mines, avalanche forecast centers, guides, and other snow professionals.

Another benefit of a shared data network is that users can be able to view snowpack and other local measurement from other users in their vicinity or far away, further informing their decisions through the backcountry. For example, one user planning to go to a certain backcountry area may notice multiple measurements from other users in the same location earlier that day. If the measurements convey dangerous information, this individual may be able to decide not to go without ever even setting foot on the slope.

Furthermore, geolocation data integration with mobile mapping and GIS technologies can allow aggregation of historic avalanche data to form cold and hot zones of avalanche activity—this can be viewed at any time, not only by individual users but also for scientific and weather research purposes among others. The data can be mapped in one, two, or three dimensions and can even help professionals identify weak areas within the snowpack which may be more effectively targeted by explosives, thereby improving avalanche control precision and reducing costs.

Lastly, for professionals and more advanced recreational users, a software package can allow users to download data from the device to their computer where they are able to do more complex snow science analytics.

FIG. 18 shows the information flow for how the system sources data from the hardware device 1800 for the online database, according to some aspects of the present disclosure. Once the user 1802 has transferred test results from device 1800 to their mobile device 1502 as described in steps 1426 and 1428 of FIG. 14, mobile device 1502 can send test results to server 1804 via a wireless network transceiver 1806. As discussed above, test results can include any measurement taken by the device 1800, including, without limitation, a profile of snow hardness as a function of depth, a profile of snow temperature as a function of depth, a profile of grain size as a function of depth, local ambient temperature, humidity, slope aspect, or inclination. Server 1804, which may include at least a processor, an internal memory, and at least one interface for receiving and transmitting data, functions as a host for the data collected by the hardware device 1800 by storing the collected data in the internal memory for later retrieval. Server 1804 also can receive and record information regarding the source of the collected data, including a unique identifier corresponding to the source device 1800, a unique identifier corresponding to user 1802, the date and time the data was collected by device 1800, the date and time the data was received by the server 1804, and the geographical location corresponding to the collected data (i.e., where the test results were taken).

Server 1804 may receive similar test results and information from multiple users, perhaps simultaneously. Furthermore, server 1804 may also analyze information from a single user or from multiple users to draw inferences and conclusions about the degree of avalanche risk in a certain area. For example, if server 1804 detects that an anomalously large number of test results from in and around a specific geographic area indicate a high avalanche risk, server 1804 may determine that that specific geographic area poses a high avalanche risk. Server 1804 may also determine

that a high avalanche risk exists for a geographic area for which it has not received any data by extrapolating from data received regarding neighboring geographic areas. Server 1804 may also be configured to receive information from other information sources, such as weather-related information (e.g., temperature, humidity and/or wind-speed information) or alerts (e.g., snowfall warnings) from weather stations or sensors, and to factor in such information when determining the degree of avalanche risk for a specific geographic area. If server 1804 determines that a specific geographic area poses a high avalanche risk, server 1804 may be configured to proactively send an alert to, for example, users' mobile devices, weather forecasting centers, avalanche forecasting centers, ski resorts, alpine mines, departments of transportation, and other recipients. Alternatively, if server 1804 receives a safety warning published by avalanche forecasting centers or other information outlets, the server 1804 may forward the safety warning to all of the recipients listed above.

Other consumers can pull in data from the server 1804 via, for example, a mobile device 1502, which effectively allows users to share their data with others. Furthermore, avalanche forecasting centers 1808, ski resorts 1810, and other recipients (such as alpine mines, departments of transportation, etc.) can pull in the data stored on the server 1804.

FIG. 19 shows an example user interface for a mobile-device-based application to view data collected by the device, according to some aspects of the present disclosure. The mobile-device-based application in this example may be capable of receiving test results directly from a user's snow-measurement device over a short-range communication link such as Bluetooth, WiFi or NFC, as described above. The mobile-device-based application in this example may also be capable of receiving test results from server 1804 over a wireless network, and sending test results to server 1804 over the wireless network. An area map 1900 is visible on the mobile device screen with markers 1902 indicating locations where device measurements have been taken. Markers 1902 may correspond to device measurements taken by the user's own device or to measurements taken by other user's which have been downloaded from server 1804. Users can press the filter button 1904 to filter the displayed results based on their associated metadata, such as user type (recreationalist vs. professional), time of measurement, altitude of measurement, and other parameters. Users also can be able to move the zoom slider 1906 to zoom in and out of the map, or press the my location button 1910 to jump to their current location. Sliding the map on a touch screen can also scroll to change the visible area. Quick access buttons 1908 shown at the bottom of FIG. 19 can be pressed to quickly view additional information accessible via the application, such as data collected by the currently logged-on user, most recent tests, or safety warnings published by avalanche forecast centers or other information outlets. Other interfaces can exist to show data in list form, and markers can be clicked on to show detailed snowpack information represented in ways as described by FIG. 17. A similar interface can also be accessed via a web application or tablet.

The subject matter described herein can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structural means disclosed in this specification and structural equivalents thereof, or in combinations of them. The subject matter described herein can be implemented as one or more computer program products, such as one or more computer programs tangibly embodied in an information carrier (e.g.,

21

in a machine readable storage device), or embodied in a propagated signal, for execution by, or to control the operation of, data processing apparatus (e.g., a programmable processor, a computer, or multiple computers). A computer program (also known as a program, software, software application, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file. A program can be stored in a portion of a file that holds other programs or data, in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

The processes and logic flows described in this specification, including the method steps of the subject matter described herein, can be performed by one or more programmable processors executing one or more computer programs to perform functions of the subject matter described herein by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus of the subject matter described herein can be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processor of any kind of digital computer. Generally, a processor can receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for executing instructions and one or more memory devices for storing instructions and data. Generally, a computer can also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. Information carriers suitable for embodying computer program instructions and data include all forms of nonvolatile memory, including by way of example semiconductor memory devices, (e.g., EPROM, EEPROM, and flash memory devices); magnetic disks, (e.g., internal hard disks or removable disks); magneto optical disks; and optical disks (e.g., CD and DVD disks). The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

To provide for interaction with a user, the subject matter described herein can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying information to the user and a keyboard and a pointing device, (e.g., a mouse or a trackball), by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well. For example, feedback provided to the user can be any form of sensory feedback, (e.g., visual feedback, auditory feedback, or tactile feedback), and input from the user can be received in any form, including acoustic, speech, or tactile input.

The subject matter described herein can be implemented in a computing system that includes a back end component (e.g., a data server), a middleware component (e.g., an application server), or a front end component (e.g., a client

22

computer having a graphical user interface or a web browser through which a user can interact with an implementation of the subject matter described herein), or any combination of such back end, middleware, and front end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network ("LAN") and a wide area network ("WAN"), e.g., the Internet.

It is to be understood that the disclosed subject matter is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The disclosed subject matter is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other structures, methods, and systems for carrying out the several purposes of the disclosed subject matter. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the disclosed subject matter.

Although the disclosed subject matter has been described and illustrated in the foregoing exemplary embodiments, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the details of implementation of the disclosed subject matter may be made without departing from the spirit and scope of the disclosed subject matter, which is limited only by the claims which follow.

The invention claimed is:

1. An apparatus for measuring snow structure and stability comprising:

a sensing unit for probing a layer of snow, the sensing unit configured to sense a resistance to penetration; an optical flow sensor disposed in the sensing unit and configured to capture a series of images as the optical flow sensor is inserted progressively deeper into the layer of snow; and a processor configured to

determine a depth of penetration based on the series of images captured by the optical flow sensor; and determine a profile of penetration resistance according to depth based on the resistance to penetration sensed by the sensing unit.

2. The apparatus of claim 1, wherein the sensing unit comprises a tip having an inner wall defining a tip cylinder, a resistance sensing element disposed within the tip cylinder, and a weather-sealing filler which fills a space between the resistance sensing element and the inner wall.

3. The apparatus of claim 1, further comprising a pole having a length, a first end, and a second end, wherein the sensing unit is disposed at the first end of the pole.

4. The apparatus of claim 3, comprising a range sensor disposed proximate the second end of the pole configured to measure a distance between the range sensor and a surface of the layer of snow, wherein the processor is configured to determine the depth of penetration based at least in part on the distance measured by the range sensor.

5. The apparatus of claim 4, wherein the range sensor is configured to measure distance using sound waves.

23

6. The apparatus of claim 4, wherein the range sensor is configured to measure distance by transmitting and receiving a beam of radiation.

7. The apparatus of claim 1, wherein the sensing unit comprises a strain sensor comprising at least one of a strain gauge and a piezoelectric based force transducer. 5

8. The apparatus of claim 7, wherein the sensing unit comprises a resistance sensing element positioned adjacent to a diaphragm on which the strain sensor is arranged, wherein the diaphragm is configured to distort when the resistance sensing element encounters resistance, and wherein the strain sensor is configured to measure the distortion of the diaphragm. 10

9. The apparatus of claim 1, wherein the sensing unit comprises a resistance sensing element positioned adjacent to a pressure cavity filled with at least one of a liquid, an elastomer, and a gel, and a pressure sensor configured to measure a change in pressure in the pressure cavity when the resistance sensing element encounters resistance. 15

10. The apparatus of claim 1, wherein the sensing unit comprises a magnetic member that is configured to displace when the sensing unit encounters resistance, and a magnetic field sensor that is configured to measure the displacement. 20

11. The apparatus of claim 1, comprising an accelerometer, wherein the processor is configured to determine the depth of penetration based at least in part on an acceleration measured by the accelerometer. 25

12. The apparatus of claim 1, wherein the sensing unit comprises an overload bumper which prevents damage to the sensing unit. 30

13. The apparatus of claim 1, comprising a data display screen operably connected to the processor.

14. The apparatus of claim 1, comprising a wireless communication device operably connected to the processor and configured to automatically determine the geographical position of the apparatus. 35

15. The apparatus of claim 1, comprising a wireless communication module operably connected to the processor for communicating with at least one of a wireless data network and a mobile device.

24

16. A method for measuring snow structure and stability comprising:

- (a) sensing, at a probe while being inserted progressively deeper into a snow layer, a resistance to penetration;
- (b) capturing, using an optical flow sensor disposed in the probe, a series of images as the optical flow sensor is being inserted progressively deeper into the snow layer;
- (c) determining a depth of penetration based on the series of images captured by the optical flow sensor; and
- (d) repeating steps (a)-(c) to determine a profile of penetration resistance according to depth based on the sensed resistance to penetration and the determined depth of penetration.

17. The method of claim 16, comprising:

determining to start a test based on at least one of a sensed resistance to penetration and input from the optical flow sensor; and

determining to end the test when the measured depth of penetration decreases or remains constant for a predetermined period of time.

18. The method of claim 16, comprising averaging the sensed resistance values within a predetermined threshold of each other.

19. The method of claim 16, comprising identifying, in a computer processor, areas in the profile of penetration resistance according to depth in which the sensed resistance drops by a predetermined percentage within a predetermined depth as an area indicative of a high avalanche risk.

20. The method of claim 16, comprising:

calculating a penetration speed; and

adjusting the sensed resistance to penetration based on the calculated penetration speed.

21. The apparatus of claim 2, wherein the weather-sealing filler is configured to deform to allow the resistance sensing element to displace, and wherein the inner wall includes fixture grooves to prevent the weather-sealing filler from slipping inside the tip cylinder.

* * * * *